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FACTORS INFLUENCING THE FAILURE OF NAVAL BOILER TUBES.

BY LIEUTENANT A. P. CALVERT, U. S. NAVY, MEMBER.*

This paper has been prepared after an extensive study of failed boiler tubes as well as a survey of technical literature on boiler tube failures. The writer has not been satisfied with the phrase used frequently in test reports that "this boiler tube probably failed through its having been heated to the plastic state." Such a statement appears inconclusive and of little help in an attempt to analyze boiler tube failures. Accordingly, his work has been to correlate previously reported test data with independent research in order that some of the loose ends may be brought together under one cover. He recognizes that the problem of boiler tube failure is not yet completely solved. But he accomplishes a noteworthy advance toward its solution.

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I.

A boiler pressure part failure may be defined as the inability of the member to retain the pressure producing medium resulting in forced outage of the boiler. As is well known, the tubes are the most frequent source of failure and accordingly occupy the major part of this discussion.

The principal possible reasons for boiler tube failures are as outlined below.

CASUALTIES INFLUENCED BY DESIGN.

(A)—A boiler in which improper or inadequate circulation exists is incapable of operation at sustained high rates without tube failure. Dearth of water allows tubes to become overheated. These tubes ordinarily are those in the fireside rows or others of the high caliber (ratio of length to diameter) of 120, in the small tubes adjacent to the fireside rows.

(B)—Temporary slow, interrupted or retarded circulation may cause momentary overheating which, if prolonged or frequently repeated, may cause tube casualties. In this case the boiler is incapable of rapid maneuvering without jeopardizing the safety of the tubes. Temporary inadequacy of circulation results because of inertia, constricted passages, or momentary steam binding, when unusually sudden demand for accelerated circulation occurs.

(C)—Improper burner layout may enhance the possibilities of steam binding in fireside rows, or due to the simple proximity of the flames, tend to aggravate lack of circulation when dearth of water occurs as under (B) above.

CASUALTIES INFLUENCED BY MATERIAL OR CONSTRUCTION.

(A)—Tube failures may occur from improper manufacture. Die marks or other imperfections have a tendency to cause premature tube failure.

(B)—Tubes may be cracked or die marks greatly augmented at the tube ends by improper tube hardness, making rolling difficult. Scored tube ends chargeable to improper rolling, sometimes expedite tube failure.

CASUALTIES INFLUENCED BY OPERATION.

(A)—The fouling of the watersides of fireside rows with scale; particularly calcium sulphate scale, oil or grease, is one of the most prevalent causes of tube failure. The deposition of such material greatly reduces heat transfer through the tube metal, tending to cause serious overheating. In such cases blistering, oxidation, and distortion occur.

(B)—Tubes may be plugged by foreign material such as metal fragments, fiber, cloth or wood. Plugging will cause overheating by blocking circulation. The failure of tubes often occurs at points distant from the actual plugging or blocking.

(C)—Low water in any boiler will tend to cause direct overheating, even though the water level may not have been entirely lost, particularly if it is coincident with rapid maneuvering. Changes in circulation in the boiler, particularly when low water occurs during heavy rolling, with or without simultaneous rapid maneuvering, may tend to permit overheating of the tubes, with subsequent failure.

(D)—Continual lighting off of the boiler with the main stop closed, bringing pressure up rapidly, as might be done in cases of emergency, may tend, if frequently repeated, to warp the fireside generating tubes of certain types of boilers.

(E)—Pitting of the waterside of tubes due to copper, improper water conditioning and entrainment of oxygen in the feed water. Pitting of the fireside surface due to an accumulation of soot plus moisture.

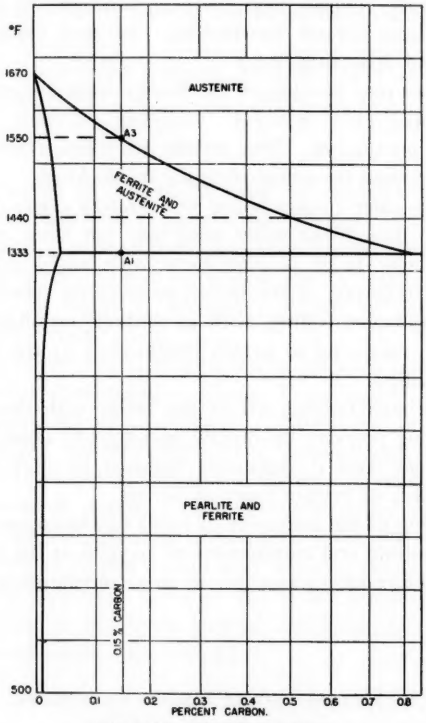
II.

The Metallurgy of Boiler Tube Steel.

No discussion of boiler tube failures would be complete without a brief review of the metallurgy of low carbon steel, including the effect of heating and cooling rates on the microstructure and hardness of the tubes.

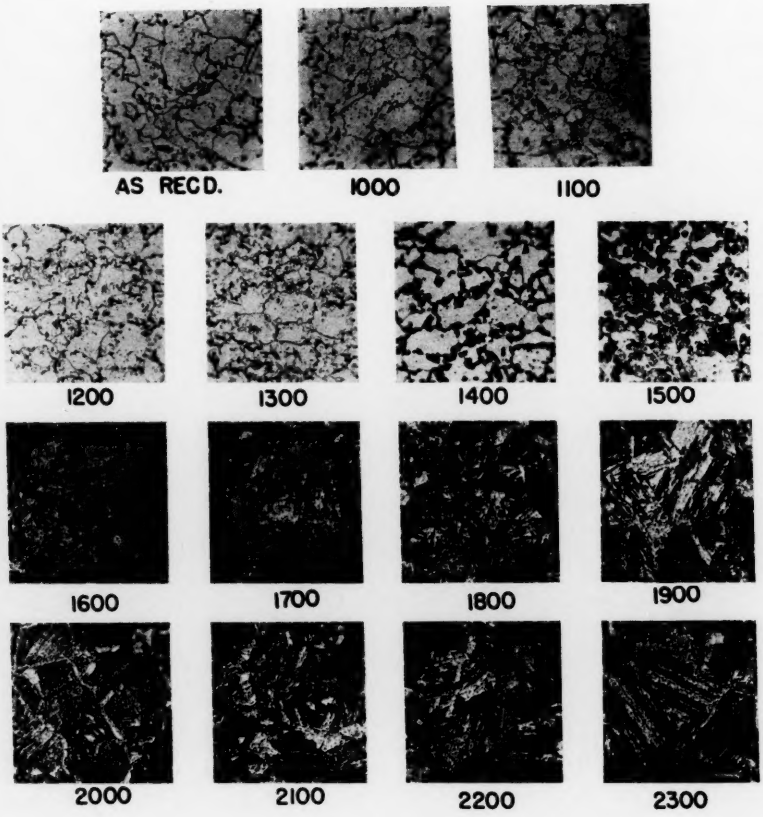
The current Bureau of Engineering Specification 44T3 (INT) of 15 October, 1937, on seamless boiler tubes, does not specify the chemical composition of the material, other than to require that it contain at least 0.10 per cent silicon and at least 0.40 per cent

manganese to insure its being produced from "killed" steel. It is customary for tube fabricators to furnish boiler tubes under the above specification with an average carbon content of 0.13 to 0.17 per cent.



IRON- CARBON EQUILIBRIUM DIAGRAM.
FIGURE 1

In analyzing boiler tube failures the metallographist keeps in mind the accompanying simplified iron-carbon equilibrium diagram, Figure 1, on which the points A_1 and A_3 mark the extent of the transformation or critical range for a 0.15 per cent carbon steel, and the temperature range 1333 degrees-1550 degrees F. In heating from room temperature through the lower critical tempera-



WATER-QUENCHED SERIES

EFFECT OF TEMPERATURE ON BOILER TUBE MATERIAL AS DETERMINED FOR 1" LONG CYLINDRICAL SECTIONS FROM 1" BOILER TUBE. ALL SPECIMENS HELD AT TEMPERATURE ONE-HALF HOUR. ALL PHOTOGRAPHS ARE OF TRANSVERSE SURFACES AT MAGNIFICATION OF 100 DIAMETERS. ALL TEMPERATURES IN DEGREES FAHRENHEIT.

FIG. 2

ture, the A_1 point, the constituents of boiler tube steel undergo an allotropic change from the substances known as "pearlite" and "ferrite" to "ferrite" and "austenite" and on passing the A_3 point, to "austenite." The reverse occurs in cooling from above the upper critical temperature. These allotropic transformations are accompanied by several property changes, among which are changes in hardness as well as microstructure. A point also to be considered in a study of the effect of temperature on the microstructure and hardness of boiler tubes is the influence upon these two properties of the rate of heating and cooling. A tube specimen quenched in water from 1550 degrees F. will not exhibit the same microstructure or hardness as, for example, a specimen air or furnace-cooled from the same temperature.

In normal operation, the temperature of the inner surface of a clean boiler generating tube is very close to that of the contained fluid. If for any reason the temperature of the metal increases to the point at which rupture takes place, the effect of the water and steam leaving the boiler at this point is to quench or rapidly

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EXPLANATION OF PHOTOMICROGRAPHS ON FIGURE 2.

The photomicrographs for pictures 1000 degrees and 1100 degrees F. show no change from the "As Received," whereas pictures 1200 degrees and 1300 degrees F. indicate that some incipient recrystallization has begun. The dark areas represent pearlite distributed throughout the white ferrite. After the lower critical temperature (1333 degrees F.) has been passed, segregation of the pearlite constituent at the ferrite grain boundaries is noted at 1400 degrees F. The specimen quenched from 1500 degrees F. indicates still further segregation of the pearlite. At the upper critical temperature (1550 degrees F.), the segregation has been completed and the 1600 degrees F. picture shows the microstructure to be what is known as sorbite. The remainder of the pictures up to the one for the specimen quenched from 2300 degrees F. shows that above the upper critical temperature little change in microstructure takes place, except for the increase in grain size at the higher temperatures. In the 2300 degrees F. picture, however, it will be noted the existence of so-called "spiney" ferrite.

cool the metal to a point at least below the lower critical or A_1 point (1333 degrees F.). The result of this quenching action is the arresting of the allotropic change at or near the quenching temperature so that an examination of the microstructure indicates the temperature at which the rapid cooling originated.

In an attempt to add further to the study of boiler tube failures, the Naval Engineering Experiment Station heated one-inch cylindrical samples of one-inch boiler tubing (0.13 per cent carbon) to temperatures ranging from 1000 degrees F. to 2300 degrees F. for one-half hour. One series was quenched in water at 70 degrees F. from the different temperatures, another set was air-cooled, and the third set was furnace-cooled. After polishing and etching, the microstructures of the various samples were photographed and the hardness thereof determined on the 30T scale of the Rockwell Superficial Hardness Tester, the several readings being converted into Brinell numbers.

Figures 2, 3 and 4 indicate the microstructure of the water-quenched, air-cooled and furnace-cooled series, respectively.

The hardness survey indicated above resulted in the curves of Figure 5. Here it will be noted that the Brinell number of the specimens before heat-treatment, was 70 to 80, being somewhat softer than that usually experienced. In a large number of tubes hardness-tested to date, the average Brinell number was found to be 100. Probably because of the thin sections that were being heated, with their attendant rapid loss of heat, the maximum hardness of the water-quenched series is found to be developed at 1600 degrees F. instead of at the upper critical temperature (1550 degrees F.).

Approximate grain size determinations, according to the American Society for Testing Materials' standards, Figure 6, indi-

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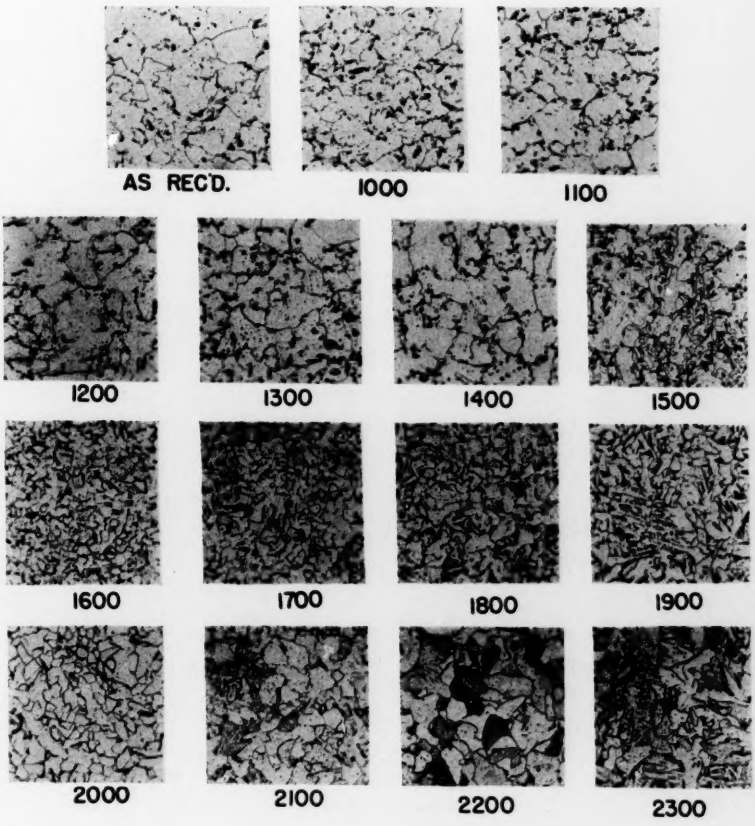
EXPLANATION OF PHOTOMICROGRAPHS ON FIGURE 3.

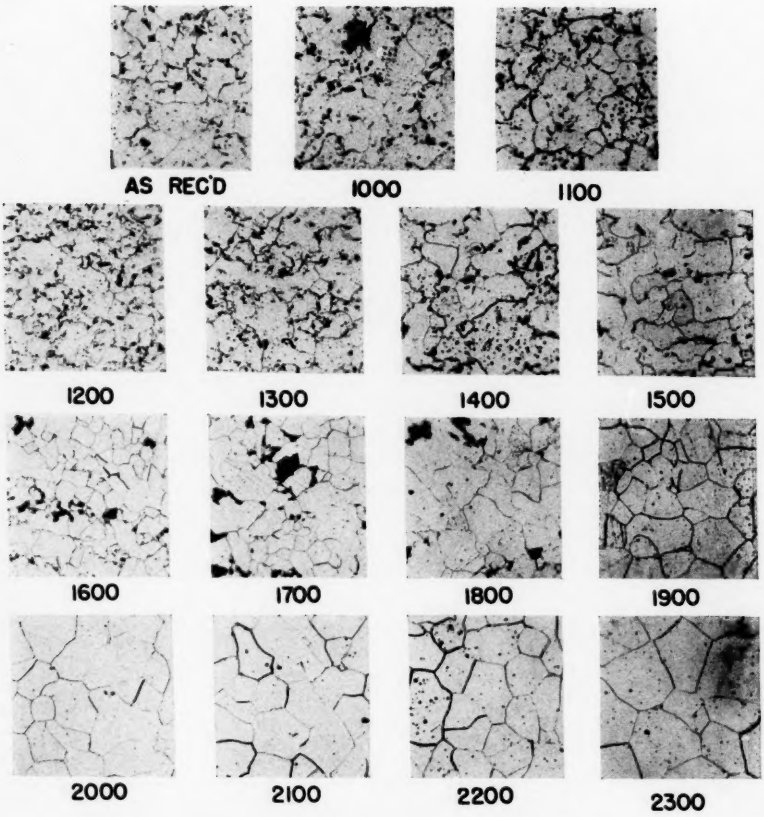
Little change is noted in the microstructure until 1500 degrees F. is reached, at which time recrystallization is noticeably advanced and is completed on passing the upper critical temperature. The remainder of this series indicates the grain growth taking place at the higher temperatures.



AIR-COOLED SERIES

EFFECT OF TEMPERATURE ON BOILER TUBE MATERIAL AS DETERMINED FOR 1" LONG CYLINDRICAL SECTIONS FROM 1" BOILER TUBE. ALL SPECIMENS HELD AT TEMPERATURE ONE-HALF HOUR. ALL PHOTOGRAPHS ARE OF TRANSVERSE SURFACES AT MAGNIFICATION OF 100 DIAMETERS. ALL TEMPERATURES IN DEGREES FAHRENHEIT.

FIG. 3



FURNACE-COOLED SERIES

EFFECT OF TEMPERATURE ON BOILER TUBE MATERIAL AS DETERMINED FOR 1" LONG CYLINDRICAL SECTIONS FROM 1" BOILER TUBE. ALL SPECIMENS HELD AT TEMPERATURE ONE-HALF HOUR. ALL PHOTOGRAPHS ARE OF TRANSVERSE SURFACES AT MAGNIFICATION OF 100 DIAMETERS. ALL TEMPERATURES IN DEGREES FAHRENHEIT.

FIG. 4

cate the same shifting of the peak of the curves illustrated in Figure 5. For the water-quenched series it was found impossible to make accurate grain size determinations for quenching temperatures above 1700 degrees F.

A part of the analysis of each boiler tube failure at the Naval Engineering Experiment Station is a hardness survey made of various parts of each failed tube submitted. A curve of hardnesses compiled from test data, converted from the Rockwell 30T and 30N scales into Brinell numbers, plotted against probable quenching temperature as noted by an examination of the microstructure of the boiler tube, is pictured in Figure 7. This type of curve is useful in quickly locating the critically overheated portion of a boiler tube where such is not indicated by a rupture, without having to laboriously dissect the tube, polish and etch the specimens and examine each one under the microscope. Comparing Figure 7 with Figure 5 shows that the tube samples heat-treated to furnish the photomicrographs for the water-quenched series had an average Brinell number one hundred twenty points higher than for the corresponding temperatures on Figure 7. It would thus appear that a critically overheated boiler tube, while exhibiting the same microstructure as the water-quenched series of Figure 7, undergoes a softening stage equivalent to a drawing temperature of about 1350 degrees F., probably occasioned by the residual heat left in the refractory of the furnace.

EXPLANATION OF PHOTOMICROGRAPHS ON FIGURE 4.

The pictures of this series are noticeably similar to those of Figure 3 up to 1600 degrees F. Here the pearlite segregation becomes much more pronounced and decarburization has begun. The latter increases up to 1800 degrees F. and is completed at some point between 1800 degrees and 1900 degrees F. Above this temperature the greatly decarburized material increases in grain size.

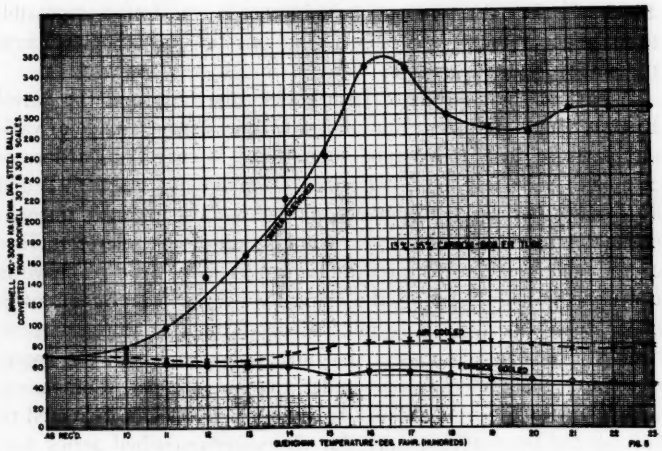


FIGURE 5.

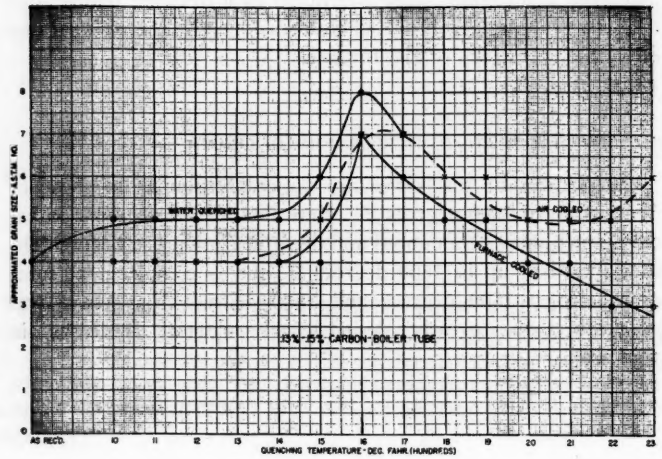


FIGURE 6.

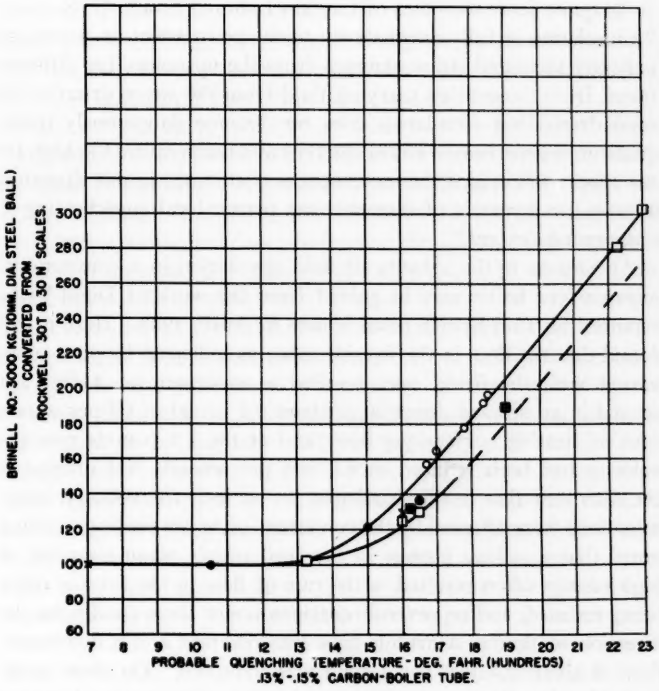


FIGURE 7.

III.

CASUALTIES INFLUENCED BY DESIGN.

CIRCULATION.

As defined by Rear Admiral O. L. Cox, U. S. Navy, "Circulation in a boiler is continuous movement of fluid across surfaces, the other sides of which are exposed to hot gases." In the above definition, "fluid" is the material in circulation and may be either a liquid or a gas or a mixture of the two. To further fulfill the requirements of the definition the "fluid" movement must be continuous, not just pulsating.

To quote from the notes of Captain Lybrand Smith, U. S. Navy, "Circulation is fully adequate up to the point when no water and only dry saturated steam emerges from the upcomers (as differentiated from those tubes carrying fluid from the steam drum to the mud drum) but circulation does not become dangerously inadequate until superheated steam emerges at a temperature too high for the tubes:—*Provided* the movement is continuous in one direction, as stops or reversals of direction can permit local superheating to a dangerous extent."

An idea as to the velocity of fluid circulation in a conventional express type boiler may be gained from the work of Dight [1] who reported tests on British naval boilers in April, 1933. Here it was found that the flow in the fireside tubes as indicated by pitot tubes varied with the firing rate, reached a maximum of 4 feet per second in an upward direction at about 0.2 pound of oil per square foot of heating surface per hour and at the 1.2 pounds rate the velocity had been reduced to 2.5 feet per second. Of interest is the discovery that in this particular set of tests the velocity determinations were affected by the conditions of boiler feeding, it being noted that a sudden change in the feed supply when steaming at high ratings often resulted in the rate of flow in the fireside tubes being reduced, and on several occasions under these conditions the direction of flow in a fireside tube was reversed and a downward flow of about 2.5 feet per second was indicated. On these occasions the direction of the flow persisted in the reverse direction until the firing rate was materially reduced, when the flow changed to an upward direction and quickly returned to normal conditions.

Another reported instance [2] of the capriciousness of natural circulation is of interest because of the fact that the boiler in question is similar in circulation characteristics to the A type boiler. Here tubes in the generating tube banks were being lost through overheating at points about 30 inches below one of the steam drums. Thermocouples welded to the tubes in the affected area indicated metal temperatures from 600 to 1200 degrees F. continuously at the water level then considered normal. It was also found that the temperature of all tubes could be kept normal, 360 to 460 degrees F. by maintaining the water sufficiently high in the center steam drums. It was reported that the rapidity at which

the tube temperatures increased and decreased was surprising. Many times a change of nearly 800 degrees F. occurred in less than one minute and this was brought about by raising or lowering the water level in the gage glass only one-half inch.

Since early in 1937, failed boiler tubes have been received at the Naval Engineering Experiment Station from time to time in which the cause or causes of the casualty have not been readily apparent. Where removed from an A type boiler, in every case the tubes were from a location within two rows of the furnace and they were usually from near the back of the furnace. In addition, the ruptures had all occurred within thirty inches of the steam drum. The watersides of the tubes were invariably free of sulphate or silicate scale though patches or strips of a hard, black, shiny, tightly adherent scale were often found in the vicinity of the rupture. This scale, in amounts insufficient for chemical analysis, was found to be magnetic and was probably mill scale, Fe_3O_4. Further visual examination disclosed no appreciable die marks or other manufacturing defects, no great amount of pitting, and no wall thinning through oxidation. Chemical analyses of the boiler tubes, where made, and physical tests proved the material to conform to current specifications. From an examination of the ruptures themselves, it was noted that there appeared to be two different types. In one type the edges of the rupture were drawn down to an even knife edge reminiscent of a rupture caused by a heavy calcium sulphate waterside scale. Another type of failure noted infrequently was distinguished by no great thinning of the lips of the rupture but instead of a knife edge the edges were quite ragged. This condition was accompanied by short, irregular, discontinuous, longitudinal cracks on the interior of the tube extending from the point of origin of the failure.

Upon examination under the microscope of sections adjacent to the rupture, regardless of its type, the microstructure showed that the material had been quenched or rapidly cooled from above the lower critical temperature, 1333 degrees F., and more usually from above the upper critical temperature, 1550 degrees F. In some instances, the microscope disclosed a critically overheated and quenched condition throughout an arc of less than 90 degrees with the remainder of the transverse section little altered in microstruc-

ture. Several warped, but not ruptured, A row tubes submitted for examination showed an overheated waterside skin on the side of the tube away from the fire near the steam drum, with the rest of the tube normal in all respects. Sections of the tubes removed a few feet down from the failed or warped portions exhibited a practically unaltered microstructure discounting the possibility of stoppage of the tube during operation. Figure 8 and its explanatory foresheet indicate the microstructures for a typical ruptured boiler tube.

From the above and subsequent test work, it has become the theory of the Naval Engineering Experiment Station that such failures are due to conditions of fluid circulation which do not meet the definition and premises set forth within the first two paragraphs of this chapter. Though impractical to prove at this time, it is the opinion of this writer that the type failure characterized by thick lips is the result of pulsating or intermittent circulation over an appreciable length of time which allows the tube metal to become heated to temperatures above 1000 degrees F., at which temperature creep of the tube material takes place. The other type of failure with the knife-edged lips is believed to be the result of an operating condition in which the tube becomes steam bound in its upper reaches, allowing the tube metal temperature to rise well

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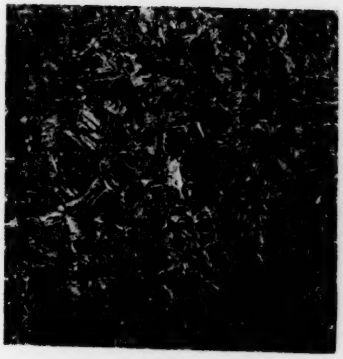
EXPLANATION OF PHOTOMICROGRAPHS ON FIGURE 8.

Photomicrographs indicating microstructure of a typical ruptured Naval boiler tube at various distances from the rupture. All photographs are of transverse surfaces at 100 diameters magnification. Rupture was of the thick-lipped type, See Figure 9, and took place twenty-two inches from the rear or uptake header.

1. Microstructure at the rupture. Note similarity to 1800 degrees F. picture of Figure 2.
2. Microstructure 14½ inches from rupture toward water drum.
3. Microstructure of a normal unfailed tube.
4. Microstructure 48 inches from rupture toward water drum. Note similarity to 1500 degrees F. picture of Figure 2.
5. Microstructure 54 inches from rupture toward water drum. Microstructure practically normal though it resembles somewhat the 1300 degrees F. picture of Figure 3.



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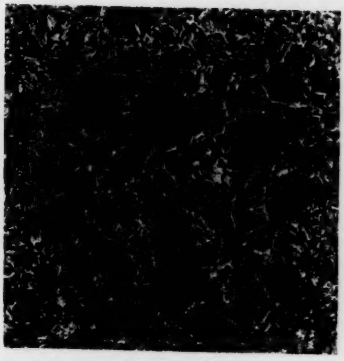

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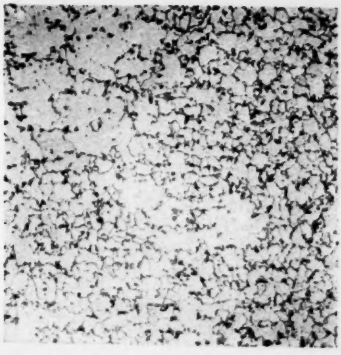

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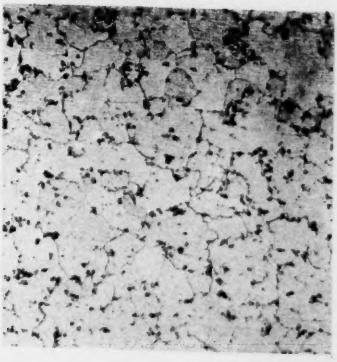

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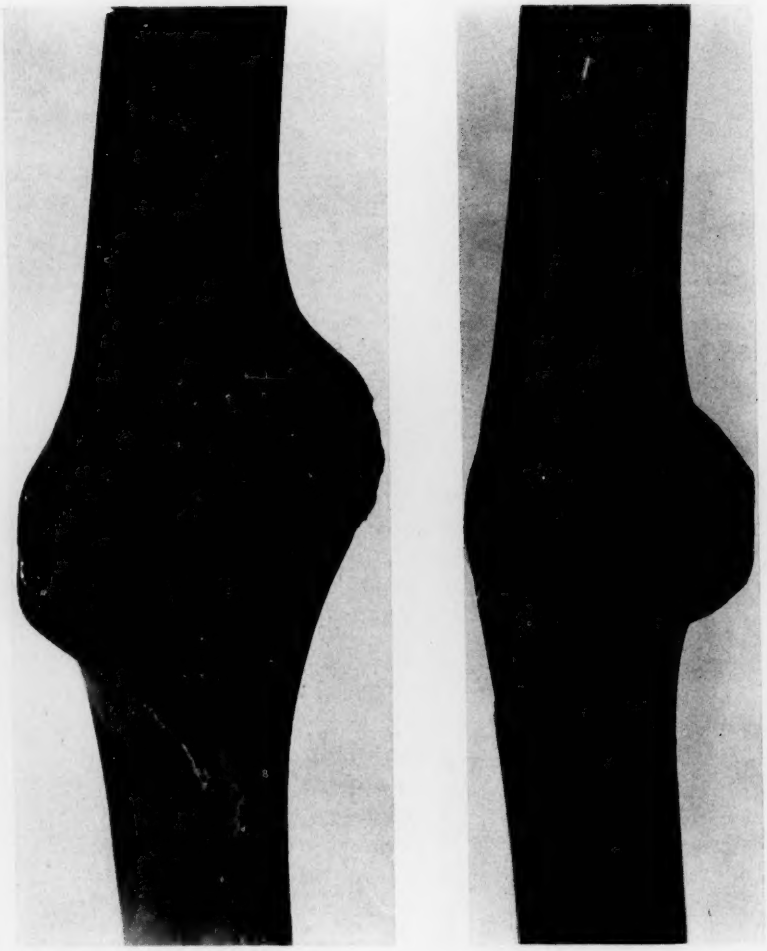
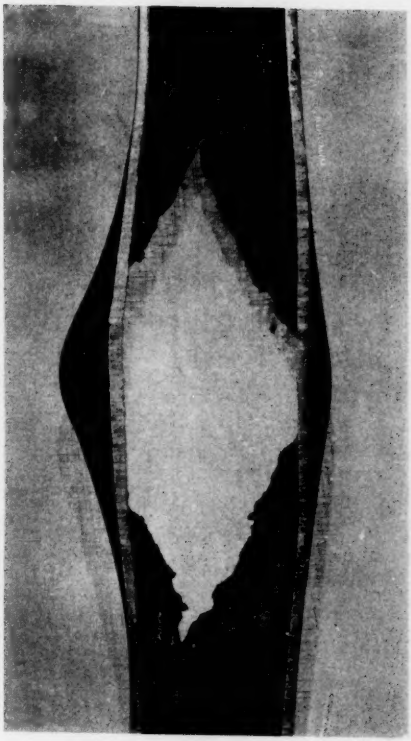
FIG. 8



THICK LIPPED TYPE

KNIFE EDGE TYPE

TYPICAL BOILER TUBE RUPTURES FIG. 9



THICK LIPPED TYPE RUPTURE
FROM WATERSIDE

FIG. 10

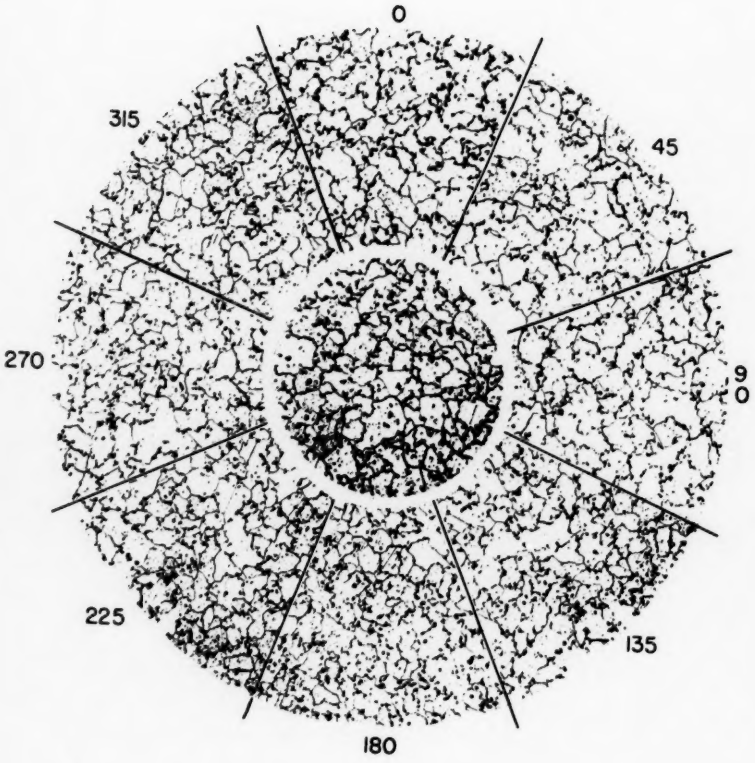


FIG. 11

above the upper critical temperature and remain there until a blister forms which subsequently bursts. Typical ruptures of the two types in 1½ inch boiler tubes are shown in Figure 9. Figure 10 indicates a thick-lipped type rupture photographed from the waterside more clearly showing the creep lines.

It is not believed to be a coincidence that ruptures of the former type are found only the side of the tube away from the fire both in the A type and SX boilers, and the knife-edge type is found facing the fire, as experiences in the marine field bear out the above findings.

In an effort to reproduce artificially the microstruture noted in the failed tubes discussed in this chapter, the following laboratory tests were performed.

A four-foot length of 1⅛ inch seamless boiler tube was held horizontally in a vise, the ends of the tube being connected to a water supply line and a discharge pipe. The water line contained a valve so that water could be admitted into the tube as desired. The upper surface of the tube was locally heated by means of an oxy-acetylene torch provided with a No. 6 tip. With this torch, approximately one minute was required to heat a spot about ½ inch in diameter to a dull red heat; and about twice this period was required to produce an orange heat. A temperature gradient in the form of a band extended around the tube from the heated spot. Thus, visible color extended approximately 45 degrees each way from the local hot spot.

For the first test, the tube was locally heated to a dull red heat estimated as 1350 degrees-1400 degrees F. The torch was then removed and the heated area allowed to cool in air. A ring section containing the heated band was removed from the tube for metallographic examination. The procedure was repeated on another section of the tube, but this time cooling was effected by introducing tap water into the tube. Other tests were made by locally heating to an orange color estimated as 1600 degrees-1650 degrees F., followed by air cooling and water quenching. Likewise, rings were taken from the heated zones of the tube for metallographic examination.

Figure 11 presents eight photomicrographs prepared from a tube ring which was locally heated to a dull red heat estimated as

1350 degrees-1400 degrees F., followed by air cooling. A representative microstructure is shown for every 45 degrees of the tube ring. The uppermost photomicrograph designated 0 represents the hottest portion of the ring, whereas the segments at 45 degrees from this position, designated 45 and 315, represent the extreme of the band showing a visible color when heated. The circular photomicrograph shown in the center of the Figure shows the microstructure for the tube material before heating. Figure 12 presents a series of photomicrographs prepared from a tube ring which was heated in the same way, but cooling was effected by introducing tap water into the tube.

It will be noted that none of the ring segments of Figure 11, except possibly the segment designated 0, reveals any appreciable change in microstructure. In the case of segment 0, there appears to be a slight segregation of pearlite at the grain boundaries. Somewhat more pronounced structural changes are noted for the corresponding ring which was water quenched, as revealed by pearlite segregation in segments designated 0 and 315 of Figure 12. The other segments show no appreciable structural change.

Similar series of photomicrographs for 1⅛ inch diameter tube rings heated locally to an orange heat, estimated at 1600 degrees-1650 degrees F., followed by air cooling and water quenching, are shown in Figures 13 and 14, respectively. As before, the photomicrographs designated 0 represents the hottest portion of the tube ring, whereas the segments designated 45 and 315 represent the structures at approximately 45 degrees from the hot spot.

It will be noted that segment 0 of Figure 13 shows fully recrystallized material of uniform grain size differing decidedly from the normal structure represented by the center photomicrographs. Likewise, segments designated 45 and 315 show alteration in microstructure in that there is evidence of incipient recrystallization. Obviously, segment 0 was heated above the upper critical temperature, and segments 45 and 315 somewhat below this temperature. None of the other five segments reveals any appreciable structural change.

As previously mentioned, Figure 14 presents photomicrographs for the ring section locally heated to an orange color, estimated temperature 1600 degrees-1650 degrees F., followed by water

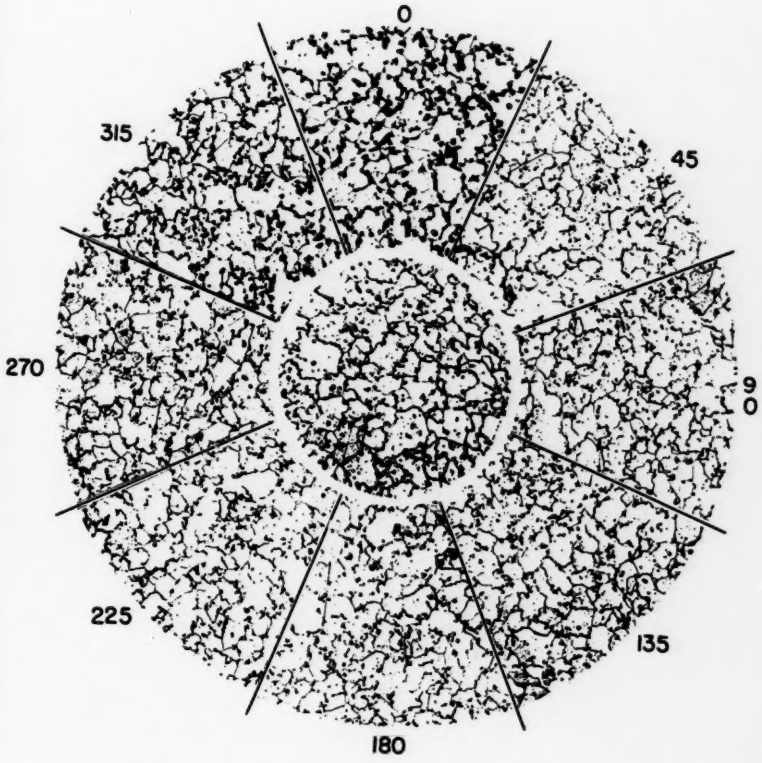


FIG. 12

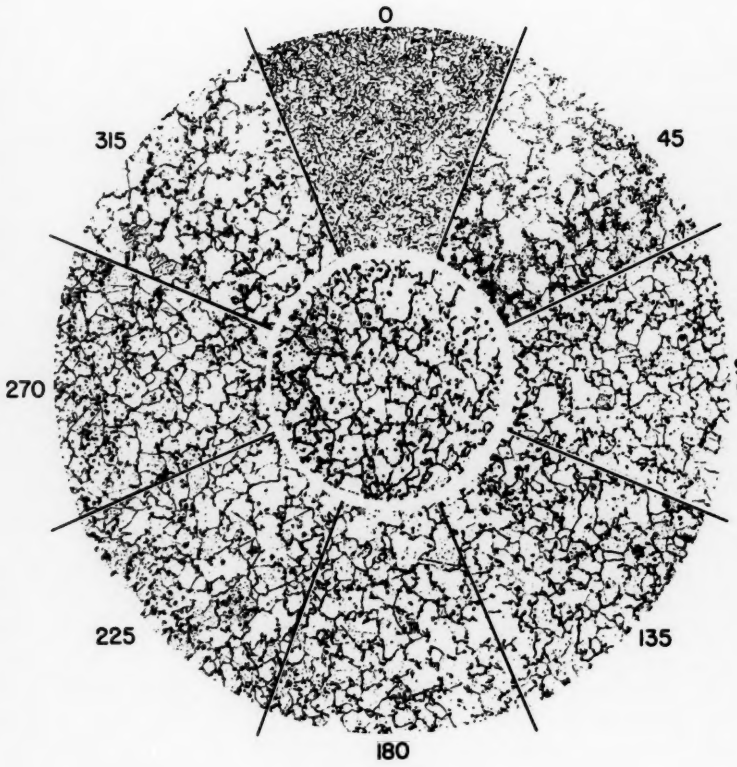


FIG. 13

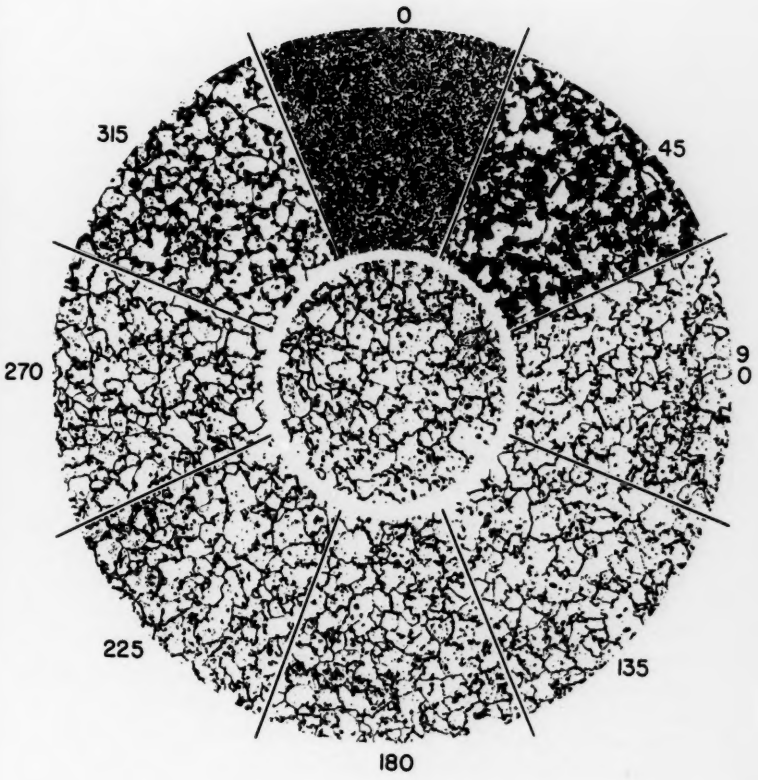


FIG. 14

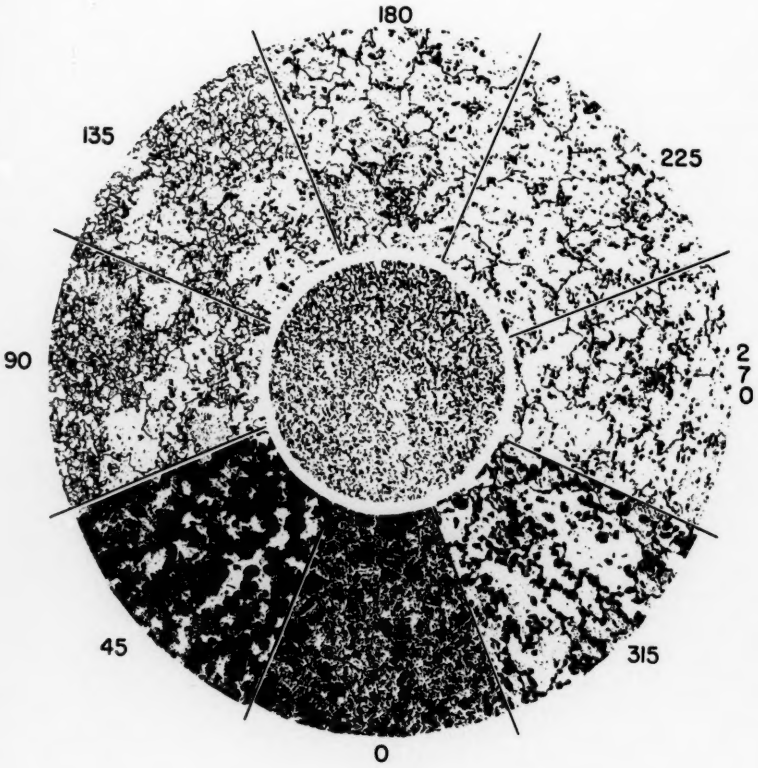


FIG. 15

quenching from the inside of the tube. Segment 0 of Figure 14 shows a sorbitic microstructure characteristic of low carbon steel quenched from above the upper critical temperature. Segments designated 45 and 315 show structural changes produced by subcritical temperatures. These photomicrographs show decided segregation of the pearlite constituent. The tube ring area represented by the photomicrograph designated 45 received a somewhat higher temperature than did segment marked 315. From previous experiments, it is estimated that the tube ring at point 45 received a temperature of 1500 degrees F. and the area at point 315 somewhat lower. No appreciable structural changes are noted for the other five segments of the tube ring.

The structural changes for a locally overheated boiler tube previously shown were obtained by artificial means. Hence, it remains to show that similar changes may occur in boiler tubes under some conditions of operation.

Figure 15 presents a series of photomicrographs prepared from a ring of a failed 2-inch boiler tube which was located in the second row from the fireside of a Naval boiler. This section was selected for illustration, since a variation in microstructure occurred from one side of the tube to the opposite side.

The photomicrographs of Figure 15 are arranged opposite from those previously shown, since the fireside of the tube is represented by the lower portion of the ring designated 0. The circular photomicrograph located in the center of the Figure represents the normal structure of the tube. The area represented by this photomicrograph was located several feet distant from the overheated areas. The normal grain size for this tube is small and fairly uniform, indicating that the tube was finished by cold drawing, a process which is deemed necessary in order to meet the tolerance requirements for tube size. The microstructure represented by segment 0 obviously was heated within the upper critical temperature range, followed by rapid cooling. Likewise, segments 45 and 315 indicate temperatures within the red heat range followed by rapid cooling. Segments from 90 to 270, inclusive, in a clockwise direction, reveal a large grain size as contrasted to the small grain size of the normal material represented by the center photomicrograph. Apparently, this area was critically heated but slowly cooled.

Possibly the tube in this area had been repeatedly heated and slowly cooled. However, it is certain that section 0 was heated within the upper critical temperature range and quickly cooled, while areas represented by segments 45 and 315 were heated within the red heat range and quickly cooled. It is pointed out that greater differences for the rates of cooling probably exist for actual boiler tubes than for experiments performed in the atmosphere, since the furnace environment would condition the rate of cooling for a tube that had been heated to the critical temperature. Regardless of these differences, the similarity between segments designated 0, 45 and 315 of Figure 14 and the corresponding numbered segments of Figure 15, is striking.

IV.

Casualties Influenced by Material or Construction.

Internal and external material defects due to manufacture.

Undetected internal and external defects in boiler tubes, as a result of the fabrication process are probably not usually of sufficient importance by themselves to cause failure under operating conditions. Coupled with other possible causes of failure however, manufacturing defects may become of major importance. An internal longitudinal score in a boiler tube is a well-known "stress-raiser" and becomes an excellent point of attack for corrosion. Waterside mill scale left as a result of inadequate pickling may reduce the heat transfer rate somewhat with a corresponding increase in metal temperature, particularly if accompanied by direct flame impingement and stagnant or pulsating circulation.

The issuance of Bureau of Engineering Specification 44T3 (INT) of 15 October, 1937, covering Seamless Boiler Tubes, extended the method of inspecting boiler tubing to include the expanding and flanging of a two-inch long coupon cut from each end of each tube over a polished steel cone having an included angle of 60 degrees until the total expansion is 30 per cent. Each coupon is then upset between two parallel plates until the distance between the plates is 1¼ inches. This operation produces a flange on the end of the coupon equal to 150 per cent of the diameter of the tube.

The chief advantage of the above expanding and upsetting test over the flattening test previously employed is that the specimens tested are more easily examined. Unless the flattening test coupons are all opened, which was not required under previous specifications, interior defects such as laps and seams may escape detection.

Visual examination methods must still be relied upon for the elimination of seamless tubes showing excessive mill scale, pitting and exterior surface roughness. Improved methods of boiler tube manufacture and subsequent final cold drawing operation, in order to insure the required tolerances, should contribute to the elimination of the more serious internal and external defects formerly encountered in boiler tubing.

If the tubes after final drawing are not properly annealed the result may be augmented die marks, cracked tubes, or an excessive amount of mill scale on exterior and interior surfaces. Improper tube hardness makes for difficult rolling with the danger of circumferential cracking at the tube sheet.

The use of resistance welded boiler tubes with careful inspection of the strip material before fabrication, would probably prevent the acceptance of tubes containing even minute waterside surface imperfections.

OTHER CAUSES OF TUBE FAILURE INFLUENCED BY DESIGN AND CONSTRUCTION.

The causes of natural circulation are very simple and well understood. The relatively cool feed water entering the steam drum, being denser than the highly heated upcoming steam and water mixture, sinks through the downcomers and rows of tubes remote from the fire to the mud or water drum and thence back to the steam drum. Following the lighting off of an express type boiler, however, and before full circulation is in effect, it will usually be found that, even after the working steam pressure is reached, there is an appreciable temperature difference between steam and water drums, leaving the tubes connecting them in a condition occasioned by thermal stresses.

Unless adequate provisions have been made for expansion under the above condition, baffles rigidly attached to the tubes may eventually cause failure of these tubes by circumferential cracking at the tube sheets.

When an A type boiler is tubed the correct procedure is to roll the tubes into the steam drum first, then into the mud drum. Owing to the greater thickness of the steam drum at the tube holes as compared to that of the mud drum, the greatest portion of the lenghtening of the tubes has taken place before they are locked into position by rolling into the mud drum. Thus boiler tubes installed in the reverse order from that above will be appreciably strained before thermal and pressure medium stresses are imposed upon them. Such a condition may cause circumferential cracking of the tubes at the tube sheet. If the tubes do not fail by cracking, should an operating condition occur that will allow the tube metal temperature to reach the plastic range 1100 degrees-1200 degrees F., tube warpage is likely to follow.

V.

Casualties Influenced By Operation.

WATERSIDE SCALE DEPOSITS.

Since September, 1936, there have been no boiler tubes received at the Naval Engineering Experiment Station for examination that exhibited any appreciable sulphate, silicate, or similar waterside scales. This is believed due to the efficient manner in which Navy Boiler Compound 1933 has performed the task of scale prevention and elimination.

The greater portion of the boiler tubes received for analysis have, however, disclosed a waterside condition briefly disclosed under the heading of "Circulation," Chapter III. In these tubes, where ruptured, there appeared patches or longitudinal strips of a thin, black, usually shiny, hard, brittle, tightly adherent scale on either side of the rupture. The sides of the openings themselves were invariably free of any scale, such having apparently been cracked off and washed free by the rush of steam and water. In no instance was there a sufficient amount of scale for ordinary macroanalysis, and microanalytical equipment is not available; though when exposed to a magnet the major portion of any one sample was attracted and thus appeared to be largely ferroso-ferric or magnetic oxide, Fe_3O_4, sometimes called magnetite.

From an examination of a large number of ruptured boiler tubes it is fairly well established that the Fe_3O_4 waterside scale is found on the side of the tube nearest the fire and usually in a strip about one inch or less in width running for varying distances on either side and beginning several inches away from the rupture. Evidence of direct flame impingement in the form of a strip of a carbonaceous deposit on the fireside of the tube is frequently, though not always, present. The microstructure of the tube metal beneath the scale may or may not be found altered, but since as will be later shown, Fe_3O_4 does form at temperatures as low as 750 degrees F., little or no alteration of the microstructure would be expected provided the metal temperature remains below the A_1 point or 1333 degrees F. However, the presence of magnetite on the waterside of a boiler tube of unaltered microstructure is believed to be a reliable temperature indicator for temperatures between 750 degrees-1333 degrees F.

As the rupture is approached from either the mud drum or steam drum end of the tube, the microstructure under the scale becomes noticeably altered, indicating metal temperatures within or above the critical range.

There is ample evidence that the oxide scale formed on heating iron in air at high temperatures, as in the rolling of steel plate, may consist of several layers. That layer adjacent to the metal has the composition of ferrous oxide, FeO. The next two layers in order are said to be ferroso-ferric, Fe_3O_4 and ferric oxide, Fe_2O_3. However, if the heating of the iron is done in the presence of steam or low oxygen content water, the resulting oxide appears to be mainly Fe_3O_4.

As far as boiler tubes are concerned, it is not believed that the Fe_3O_4 scale found was the result of excessive mill scale formed during the annealing operation of fabrication, and not subsequently removed by pickling; but was rather occasioned by a tube metal temperature sufficiently high to cause the breaking down of the water or steam in contact with the tube into hydrogen and oxygen, and the latter combining with the hot iron of the tube to form Fe_3O_4. Mill scale conforms to most of the characteristics of the scale in question and a coating of mill scale might cause a slight resistance to heat flow; but it probably would not be enough to

cause the overheated condition of the metal disclosed on making a metallographic examination of the ruptured portion. It therefore appears that the formation of the scale was more probably the effect, not the cause, of overheated sections of the tubes.

Partridge [3] states that, "It is not generally realized that, in the absence of oxygen, water will react with steel even at room temperature to produce Fe_3O_4 and hydrogen. The rate of this reaction at room temperature is, of course, very slow. Increase in temperature speeds up the reaction progressively, as might be expected." Further, "Since the resistance to heat transfer from a metal surface to water vapor is many times that of the corresponding resistance from the metal surface to boiling water, the development of a steam blanket might readily cause overheating of the metal, with ultimate failure by blistering. The overheating would tend to produce a noticeable coating of black iron oxide on the inside of the tube, but this coating would be likely to crack off near the point of rupture, as the steel expanded."

Tests at 1000 degrees-1200 degrees F. indicate that steam as water vapor dissociates to some extent into hydrogen and oxygen, the latter combining with iron to form the magnetic oxide of iron, Fe_3O_4.

At the Naval Engineering Experiment Station a study of the erosive effect of high velocity, superheated steam at 600 pounds pressure and 700 degrees F. on carbon-molybdenum steel piping, has disclosed an appreciable iron oxide film after 1500 hours of operation.

Tests [4] on the oxidation of iron turnings by steam show that if the temperature does not much exceed 572 degrees F. (300 degrees C.) the reaction is very slow, and practically ceases when the iron is covered with a film of oxide. The latter, however, does not give protection above 752 degrees F. (400 degrees C.). If this layer of scale becomes thicker the temperature increases; and consequently the danger of cracking of the protecting layer increases, due to variations in temperature, exposing the hot metal to the further action of oxygen with resulting thinning of the tube wall in the case of a boiler tube.

In another paper [5] the findings in the preceding paragraph are verified in general. Steam at temperatures from 800 degrees to

1200 degrees F. and 1200 pounds gage was passed through a .10-.20 per cent carbon steel tube, and the resulting Fe_3O_4 scale weighed to determine the oxidation rate. The data, when plotted, Figure 16, was represented by the equation $W = 5.56 \times 10^{-7} e^{0.011t}$, where W = scale formed per square inch of internal tube surface in 36 hours in grams, and t = surface temperature, degrees F. At a steam temperature of 800 degrees F., the scale formed in 36 hours was only 0.0101 grams per square inch of internal tube surface, whereas at 1200 degrees F. the scale formation increased to 0.297 grams per unit area in 23 hours, confirming the very rapid increase in oxidation rate above 1000 degrees F.

Thus, it appears conceivable that operating conditions which allow a boiler tube metal temperature above about 750 degrees-900 degrees F. are such as to make possible the formation of Fe_3O_4 at the point or region of overheating; and therefore the presence of an Fe_3O_4 scale on the waterside of a boiler is believed to be an indication that the metal temperature has appreciably exceeded the temperature corresponding to the saturation pressure of the boiler, i. e., 481 degrees F. at 600 pounds gage.

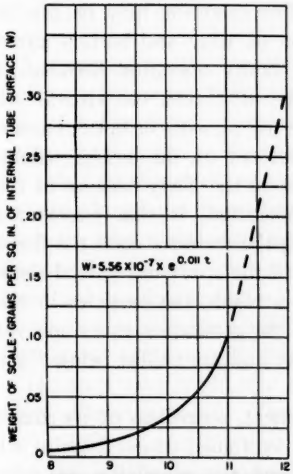


FIG. 16

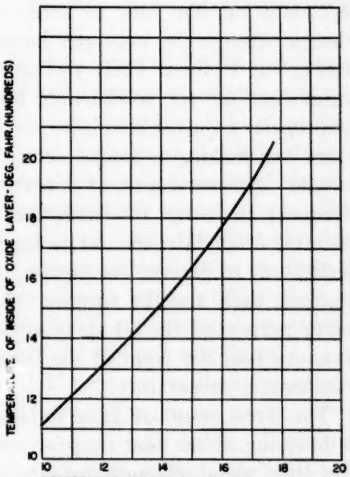


FIG. 17

A survey of technical literature relating to the thermal conductivity coefficient and porosity of magnetite scale, Fe_3O_4, in an attempt to determine if there is any great reduction in heat transfer rate through a boiler tube having such a scale on its waterside, has disclosed that there apparently are no published data on the subject. The Bureau of Mines publication, "Iron Oxide Reduction Equilibria," contains the curve from which Figure 17 has been taken. The iron oxide specimens, thickness unknown, were said to have been from a roll scale and as such may have been composed of three oxide layers. The important point, however, is that at oxide temperatures within the critical range there is only a small temperature difference between the two sides of such a scale. This is believed to verify the assumption that a Fe_3O_4 scale will not appreciably reduce the heat transfer rate through a boiler tube; it is not an important factor in the overheating of a boiler tube; and it is the result of overheating and not the cause.

FLAME IMPINGEMENT.

Hard deposits of carbon on fireside tubes and on the furnace floor and sidewalls are caused by the oil striking these surfaces before it has had time to burn. This condition may be due to design through the improper location of wing and bottom atomizers; but is more likely owing to faulty operation because of insufficient air for combustion, fouled atomizers, too viscous oil, improperly adjusted atomizers, or the use of wing or bottom atomizers for making a smoke screen instead of the smoke-making nozzle. Another cause, of importance to the Navy because of the frequent necessity for smokeless operation, is that excess air entering around the cone of oil leaving the atomizer cools the flame sufficiently to prevent combustion until the spray has passed some distance back into the furnace. As a result, the particles in the outer portion of the oil spray strike the generating tubes and refractory near the front of the furnace and are chilled below their combustion temperature.

The direct result of flame impingement, regardless of its cause, is lowering of the heat transfer rate by fouled tubes, thinning of the tube metal through oxidation, and the possibility of tube warpage or failure if the condition is accompanied by abnormal

waterside conditions such as oil, grease, or scale deposits or stagnant circulation.

In the opinion of the Naval Engineering Experiment Station a boiler tube upon which a burner flame is impinging will probably not fail provided there is a proper circulation of fluid within it over a surface free from scale, oil or grease deposits.

Before arriving at the above conclusion, tests were run in which tap water at velocities of 4.6 (full flow) and 1.75 (reduced flow) feet per second was run through three 1-inch O. D. boiler tubes prepared or selected as follows:

Tube A—Unused tube on the inside surface of which was a thin film of mineral oil.

Tube B—Used tube containing a fairly uniform scale deposit, .006 inch thick.

Tube C—Unused tube cleaned thoroughly on the inside with a solution of caustic soda.

One end of each of the above tubes was provided with a threaded connection for steam or water line. The tubes were set up in turn at an angle of approximately 45 degrees with the horizontal so that the upper end was approximately 5½ feet higher than the lower end.

A steam connection was also made to tube "C" with such pressure as to give a full flow of saturated steam at an estimated pressure of 5 pounds per square inch within the tube. With the tubes set up at an angle, as described, and with water flowing through the tube, the flame of an oxy-acetylene torch was directed onto the outside of the tube, being concentrated on one spot. The torch tip was maintained about ¼ inch from the tube surface. Two types of flame were used; namely, an oxidizing or cutting flame and a reducing flame. These flames were so adjusted as to penetrate a ⅛ inch thick mild steel plate in approximately 4 seconds for the cutting flame and 18 seconds for the reducing flame.

The tests were made near the discharge end of the tube, except when otherwise noted. The torch was directed on to the tubes under different conditions as shown in the table below. The time required for the flame to penetrate the tube was recorded. When the flame was withstood for a period of 60 seconds with no indication of failure, it was removed and the test indicated as "no failure."

Designation	*Time, seconds*	*Type Flame*	*Remarks*
A-1	6	Cutting	Full flow of water—Failure.
A-1	10	Cutting	Full flow of water—Failure.
A-1	5	Cutting	Full flow of water—Failure.
A-2	58	Reducing	Full flow of water—No failure.
A-2	60	Reducing	Full flow of water—No failure.
A-3	60	Reducing	Reduced flow of water—No failure.
A-3	60	Cutting	Reduced flow of water—No failure. Hole located near bottom of tube giving app. 3-foot head of water.
B-1	4	Cutting	Full flow of water—Failure.
B-1	3	Cutting	Full flow of water—Failure.
B-2	9	Reducing	Full flow of water—Failure.
B-2	6	Reducing	Full flow of water—Failure.
C-1	6	Cutting	Reduced flow of water—Failure.
C-1	3	Cutting	Reduced flow of water—Failure.
C-1	3	Cutting	Interrupted water circulation—Failure. Heated spot located above holes already burned through.
C-2	60	Cutting	Full flow of water—No failure.
C-2	60	Cutting	Full flow of water—No failure.
C-3	60	Reducing	Full flow of water—No failure.
C-3	28	Reducing	Interrupted water circulation—Failure. Heated spot located above holes already burned.
C-4	13	Reducing	Steam flow—Failure.
C-4	11	Reducing	Steam flow—Failure.

A = New tube containing oil film.
B = Used tube containing scale deposit .006-inch thick.
C = New tube cleaned with caustic soda.

The results show that for the tube containing the oil film, from 5 to 10 seconds were required for the cutting flame to penetrate the tube under a full flow of water. Under similar conditions, but using a reducing flame, no failure occurred after 58 to 60 seconds. Likewise, with a reducing flame and a reduced flow of water, no failure occurred in 60 seconds. One result for a reduced flow of water and supposedly a cutting flame, also withstood the flame for 60 seconds. In this case it appears that a satisfactory cutting flame was not obtained.

The tube containing approximately .006 inch thick scale failed after 3 and 4 seconds under a full flow of water using the cutting flame, while 6 and 9 seconds were required to produce failure with the reducing flame.

The clean tube with a full flow of water withstood the cutting flame for 60 seconds without failure. Similar results were obtained using the reducing flame. Under a reduced flow of water, failure occurred in 3 to 6 seconds using the cutting flame. Two of the tests are uncertain because of interrupted water circulation; note of this is made in the table.

Under steam flow, 11 to 13 seconds were required for the reducing flame to penetrate the tube wall. On account of the short time required for failure using the reducing flame, no similar tests were made with the cutting flame.

Results of heating tests presented for the clean tube, the tube containing a film of mineral oil, and the tube containing a thin scale deposit (.006 inch thick), while only approximate, show that for a clean tube using an oxy-acetylene torch, it is difficult to produce a metal temperature that is sufficiently high to show a color under conditions of a full tube of water. It was observed that once the metal attains a sufficient temperature to show a color, a very short time elapses before the tube burns through. Hence, the cooling medium must conduct the heat away so that there is no increase in metal temperature beyond that within the black heat range if overheating with subsequent burning through are to be avoided.

The tests indicate that a film of mineral oil on the interior of the tube is very effective in interfering with the heat transfer between the metal and cooling water. Interior scale deposit has a similar

effect. As might be expected, saturated steam flow is very much less effective than water flow for conducting the heat from the metal.

EXTERNAL AND INTERNAL CORROSION OF BOILER TUBES.

Tubes may suffer deterioration from a variety of causes though failures from external corrosion have become of decreasing importance since the installation of soot blowers.

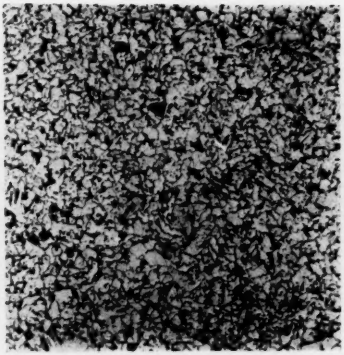
Soot which is allowed to collect and remain in boilers when idle absorbs moisture from the air, or becomes dampened from the rain, or from leaking or weeping tubes, or from moisture finding its way through the boiler casing. The moisture reacting upon the sulphur in the soot produces sulphuric acid and, if undisturbed, causes corrosion at the point of deposit which, in A type boilers, is directly above the mud drum.

In boilers employing economizers the ever-present danger of corrosion because of the lowering of the temperature of the gases of combustion below the dew point must be considered. Soot blowers, properly designed and installed and operated at intervals recommended by the Manual of Engineering Instructions, should reduce the danger of corrosion from this source to a minimum until a time when the surfaces which have been in contact with furnace gases can be cleaned by hand.

Internal corrosion of boiler tubes may be explained by one or a combination of three different theories, namely, the acid, electrolytic or differential aeration theories. Regardless of the theory considered, in a Naval boiler for which the water has been properly treated, the presence and amount of dissolved oxygen in the feed water is of major importance. Speller [6] contends that the amount of dissolved oxygen in feed water which will cause noticeable corrosion in steam boilers usually varies from 0.05 to 1 cc per liter. The maximum effect of high oxygen concentrations is naturally noted in economizer tubes and steam drums, generating tubes being attacked to a lesser degree. Hence the necessity for as complete deaeration of the feedwater as possible.

LOW WATER.

Only one case of boiler tube failure attributable to low water has been available for analysis at the Engineering Experiment



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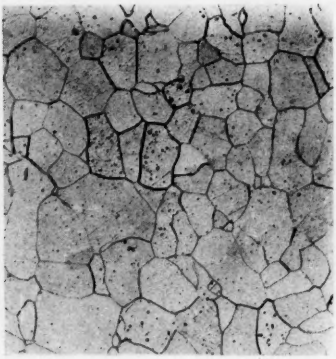

3 4

BOILER TUBE MICROSTRUCTURE
ALTERATION CAUSED BY
LOW WATER

FIG. 18

Station in recent years. Its metallurgical background is reported here largely because of its academic interest.

In the A type boiler under discussion three tubes failed. The tubes were in the fourth row from the fire, in the rear half of the boiler and all ruptures took place twelve inches from the steam drum. The ruptures were of the knife edge variety and faced the fire. A visual examination of the exterior surfaces of the tubes showed a thick, hard, black scale in the vicinity of the ruptures with a somewhat thinner, hard, black scale over the remainder of the tubes. The interior surfaces of the tubes exhibited a thin, hard, black scale. Neither fireside nor waterside scales were in sufficient amounts to allow a satisfactory chemical analysis. An unfailed sample tube from the same boiler, when sectioned, disclosed a thin, hard black waterside scale in which were visible a number of small blisters. The microstructure of this tube near the steam drum is noted in photomicrograph 3 of Figure 18. Attention is called to the marked similarity of the above photomicrograph to that of the 2300 degrees F. picture in the air-cooled series in Figure 3.

A metallographic examination of specimens taken from the ruptured tubes showed that they had been heated to well above the critical range in the vicinity of the ruptures followed by rapid cooling. Photomicrograph 1 of Figure 18 indicates the practically unaltered microstructure from a tube section near the mud drum. Photomicrograph 2 of Figure 18 indicates the microstructure found adjacent to the ruptures, which according to Bullens [7] not only indicates severe overheating, but also that the quenching temperature was at least 2300 degrees F. The spine-growth of the excess ferrite will be noted both in photomicrograph 2 of Figure 18 and in the 2300 degrees F. picture of the water-quenched series of Figure 2. The major difference between the two microstructures mentioned above is that the grain growth is somewhat greater in the case of the tubes which failed due to low water.

In conclusion, photomicrograph 4 of Figure 18 is included, having been made from a section of a fused destroyer boiler tube removed near the steam drum and obtained from an exhibit at the U. S. Naval Academy. The cause of failure in this case was also low water though the microstructure matches that of the

2300 degrees F. picture of the furnace cooled series of Figure 4. This similarity was probably due to the fact that the boiler was fired with insufficient water for a much longer period than was the case with the previously mentioned boiler, with the result that when the fires were finally extinguished there was enough heat left in the boiler metal and refractory to give a condition of very slow cooling.

GREASE, OIL AND COPPER WATERSIDE BOILER TUBE DEPOSITS

The accidental entry of oil into boiler feed water creates a serious problem for the operating engineer. Fordyce [8] states that even one part of oil per million may cause trouble. If the oil forms a film on the waterside of the tubes it will seriously reduce the rate of heat transfer with attendant metal oxidation on the fireside of the tube, early warpage and possible rupture. In addition, as stated by Evans [9] " On the waterside there may actually be increased corrosion at places where the (oil) film is discontinuous."

The title of this section on " Casualties Influenced by Operation " may appear to be grouping unrelated subjects and is offered in this manner for the purpose of encouraging comment.

A study of waterside scales from boiler tubes submitted to the Naval Engineering Experiment Station prior to 1936 indicates that where oil has been carried into the boiler with the feedwater and has been deposited on the fireside row tubes, the waterside scales from these tubes, when analyzed, indicate the presence in each case of copper oxide, CuO, in amounts as listed below:

Ship	*Copper Oxide per cent*	*Oil per cent*	*Microstructure of tube material*
A	20.39	13.19	Normal
B	19.01	27.02	Normal
C	30.79	13.15	Normal
D	14.04	0.30	Normal

The normal microstructure listed in column four, together with the warped condition of the tubes, would indicate that the oil film on the waterside had caused an elevation of the tube metal temperature to at least the plastic range 1100 degrees-1200 degrees F., but still below the A_1 point, 1333 degrees F.

The copper oxide in each of the above cases is greatly in excess of that normally found in a sulphate or silicate scale, the excess possibly being caused by the presence of the oil. One explanation for the presence of the copper oxide is found in the statement of Rowan [10], where it is noted that undecomposed grease can carry particles of brass and copper into the boiler with the feed water.

That it is possible for copper to be deposited on the waterside of a boiler tube in the metallic rather than the combined form, has been noted in three instances of warped or ruptured tubes removed from Naval boilers and forwarded to the Engineering Experiment Station. In two cases, those of ships B and C above, there were also copper oxide and oil present, but not in the same locality. Apparently the oil film inhibits the plating of copper in the metallic form. Data compiled relative to the three cases are listed on page 30.

The microstructure of the tube, under the metallic copper deposits, for the tubes from ships C and E was normal, but there were indications that the material had been heated to within the critical range in the case of ship F.

Inquiries on the subject of the deposition of metallic copper on boiler tubes addressed to the several technical societies, boiler manufacturers and public utility operators, brought forth some information but there appeared to be little agreement among the three cases reported [11] of metallic copper deposition in stationary boilers as to the cause, effect, source or remedy. The metallic copper was variously reported as found on the waterside surface in the form of straight plating; at the bottom of corrosion pits, or as finely divided metallic copper interspersed in hydrated ferrous oxide deposits in the shape of nodules. The units affected were cross drum boilers or variations thereof, and the deposits were usually found at various heights above the fire in the lower half of the tubes near and in the rear or uptake headers. The source of the copper in the above cases has been reported as coming from the rubbings from high copper alloy turbine blades, Admiralty metal evaporator tubes, copper feed piping, and the bronze impellers in boiler feed pumps. The most effective remedies applied in the several cases appear to be turbining of the boiler tubes and headers to remove existing deposits, changing to alloy steel turbine

Ship	*Type of Boiler*	*Tubes affected*	*Location of metallic copper waterside deposit*	*Type of tube failure*	*Internal tube defects noted*
C	A type Express	"A" & "B" rows near burners.	Within 24 inches from mud drums.	Extreme warpage, pinholes.	Yes, pronounced drawing scores.
E	Modified cross drum	Tubes in 2d row from furnace.	11 inches-41 inches from rear header, top of tubes.	Thick-lipped ruptures.	Minor in some tubes, none in others.
F	A type Express	"A" row tube #35.	About 36 inches from steam drum, side towards fire.	Ship reports tube warped. Amount not known.	Minor.

blades, copper-nickel evaporator tubes, corrosion-resisting steel boiler feed pump impellers; maintaining the pH value of the boiler water at approximately 11.0, and keeping the dissolved oxygen content of the feed water as low as economically possible.

The general conclusions drawn from the several industrial cases reported are that while, theoretically at least, copper was the cause of tube losses in certain cases, the copper being cathodic to the steel thus increasing the corrosion rate of the steel in the vicinity of the copper; from a practical standpoint it is believed by the operators that other factors were responsible for the trouble. It is noted that where copper deposition ceased or was lessened, regardless of the remedy used, the tube losses stopped.

There is some indication that inadequate or stagnant circulation may be a factor in metallic copper deposition in boiler tubes. In an article from "Power" [12] an examination made on a 425 pound straight tube, cross-drum boiler, indicated severe corrosion in the top rows of tubes about eight inches from the rear or uptake headers. A series of tests revealed that the primary cause of the corrosion was lack of circulation in the upper rows of tubes. Hanson [13] discusses a similar type of corrosion from the same cause. In the case discussed in "Power" the circulation deficiency was detected by means of small pipes introduced into the interior of the upper row tubes and opened to the atmosphere. It was reported that bluish colored vapor was emitted from the detectors in steam-bound tubes, while vapor from tubes filled with water was white. Further developments of this method of testing took the form of connecting the detector tubes to surface condensers and obtaining liquid samples of the tube contents. By determining the pH of the samples, the degree of circulation in each tube was indicated. A pH of 11.4, decidedly alkaline, was maintained in the boilers, as indicated by samples of blow-off taken from the lower water-wall headers and lower rows of tubes. Samples from the upper two rows of tubes, however, showed a pH of 5.6, a distinctly acid condition.

To continue further along this line, Purcell [14], in a private communication, states, "It is suggested that the alkalinity of the boiler water may determine the state of deposition (of copper), cupric

oxide depositing from alkaline water while metallic copper would tend to plate out if the water is acid." A later communication from the same source would indicate that the above statement is made with little supporting evidence and that factors other than alkalinity may play a part in copper deposition.

A study of copper concentration made from water samples obtained from various Naval vessels has disclosed the information listed below:

Ship	*Location from which sample was taken*	*pH of water sample*	*Metallic Copper, parts per million*	*Was metallic copper previously noted in boiler tubes?*
G	1	7.6*	Less than 0.05	No
H	1	6.8*	0.056	No
I	1	6.3*	0.074	No
C	1	6.47*	Less than 0.02	Yes
	2	6.50*	Less than 0.02	
	4	11.33	0.02	
E	1	9.46*	None	Yes
	2	9.48*	None	
	4	11.38	None	
F	3	6.91*	Less than 0.02	Yes
	2	7.23*	Less than 0.02	
	4	11.18	None	
J	1	7.06*	Less than 0.05	No
	2	7.54*	Less than 0.05	
	4	—	Less than 0.05	

1 = Hotwell or feed tank.
2 = Main condenser condensate.
3 = Surge tank.
4 = Boiler which has been steamed at least 200 hours and was cold when sample was taken.
* = Feed water untreated at this point.

pH is an index denoting the acidity or alkalinity of a solution. A neutral solution has a pH value of 7.0. Acid solutions show pH values less than 7.0 and alkaline solutions pH values greater than 7.0, the index numbers depending on the degree of acidity or alkalinity. Raw water freshly distilled may have a pH as low as 5.0 to 6.0. A boiler water alkalinity of .4 – .7, as required by existing instructions, corresponds to about 12.5 on the pH scale.

From the above table, in several cases the feed water before entering the boiler was slightly acid, but there appears to be no relationship between that fact and the amount of metallic copper present in either the feedwater or the boiler water. It will be noted that, contrary to the beliefs of some, there is no concentration of metallic copper in a boiler even though a trace of copper is present in the entering water.

A study of the three reported cases of metallic copper in Naval Boilers does not indicate that the situation is a serious one, there being no accelerated corrosion of the steel in the vicinity of the copper-plated portions of the tubes involved, and further, there has been no reported destruction of copper or copper alloy materials in contact with steam or feed water.

ACKNOWLEDGEMENT.

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A SHORT HISTORY OF THE NAVAL USE OF FUEL OIL.

PART IV.

By Lieutenant Commander James E. Hamilton, U. S. Navy, Member.*

In 1933, while occupying the Fuel Oil desk in the Bureau of Engineering, Navy Department, the author began the preparation of a short history of the use of fuel oil in the Navy. It was arranged chronologically and published serially in the Journal. *The first three parts covered the following periods:*

Part I, August, 1933.
I—Prior to 1902—Dabbling.
II—1902 to 1904—The Navy Liquid Fuel Board.
III—1904 to 1910—Early Application.

Part II, November, 1933.
IV—1910 to 1916—The Rise of Oil.

Part III, February, 1935.
V—1917 to 1919—The War Period.

During the preparation of Part IV, the author was detached from the Bureau. The duty which followed was of such a nature that the work had to be suspended. In picking up the thread of the history after a lapse of three years, the conclusion was reached that justice to the subject demanded broad consideration of the post-war period. This period saw more change and important development than had any previous one, particularly as affecting the present and the near future.

Thus, the sixth period will be extended to embrace the years from 1920 to 1934. It will be published serially in four issues of the Journal *as Parts IV, V, VI, and VII of the History. The author will continue his original plan in discussing this period under six subheads.*

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1. Utilization. This covers the mechanical features of handling and burning oil. It is strictly an engineering subject. The details are beyond the scope of this series and the subject will be described in a general way only.

2. Quality. This has to do with the characteristics of the oil and the specifications covering its purchase. It also will be described in a general way only.

3. Application. This covers the general methods by which the use of fuel oil has been and is applied to vessels of various types.

4. Source. This covers the natural resources of petroleum and possible substitute or replacement materials; their location, control, and Naval value.

5. Supply. This covers the events between the removal of the petroleum from its source and its acquisition by the Navy.

6. Distribution. This covers the events between the acquisition of the fuel oil and and its bunkering on board Naval vessels.

In this issue, after a short introduction to the period, subhead 1 on Utilization is presented.

THE POST WAR PERIOD.

1920 to 1934.

INTRODUCTION.

With the war ended, the American Expeditionary Forces returned from Europe, and the Army and Navy demoblized, two resultant and diametrically opposed policies arose. On the one hand, the Navy was determined that the Fleet should remain a well trained and efficient arm of the national defense and that the unpreparedness of 1916 which had proven so costly would not recur. Opposed to this policy was that of Congress, which in light of tremendous indebtedness run up during the war, was determined that the governmental budget be pared to the bone.

Large as had been the expenditures during the war, the greater part were made on projects which would not form a part of a new

prepared Navy. Many others could be retained and used but their actual post-war value to the Navy was but a fraction of the war-time cost.

It is true that much money had been spent on projects which were not vital to the prosecution of the war and which were intended to be of a permanent nature. Circumstances, however, had prevented the Navy from drawing up a complete permanent peace-time plan and carrying it to completion under the pressure of war.

With the experiences of the war behind it, the Navy was in a position to decide what was necessary to it for its share of the national defense. This was done in a general way and resulted in a number of major projects. Unlimited support in Congress would have made a properly equipped fleet and shore establishment possible. Limited, even grudgingly given, support made it possible to accomplish only the most urgent of the desired projects.

The fuel oil projects discussed below were a part of the general plan but did not obtain the full support of the Navy Department as did other matters, particularly that of personnel. Published Congressional hearings indicate that personnel matters overshadowed all others, by virtue of the force with which they were pressed, and results show little success in obtaining Congressional support for anything else.

Returning to our subject, in the light of several years, it appears to the writer that two possible plans were available to the Navy Department for setting its fuel oil course. The most desirable would have been to reconvene the 1916 fuel oil board for a revised report, revised as indicated by war experience. The alternative course would have been a militant prosecution of a plan laid down in the 1916 report.

The use of recommendations prepared by a special board rather than by any routine office or desk was desirable because no one individual or group in any part of the Navy Department had sufficient time or routine facilities for making the necessary study. The Halligan board had a very excellent membership, had made a thorough and exhaustive study, and had submitted a report based on this study and its own knowledge of naval requirements. The board had not completed all of the investigation desired and the war had furnished very valuable experience. A revision of the

report by the same board would have taken a relatively short time and would have been invaluable. A revision by another board would have taken longer because of the need for individual familiarization with the previous work but should have been equally valuable. The report without revision if formulated as a Navy Department policy and given to the proper bureaus for execution should have had very favorable results.

No Department plan was formulated, or if it was formulated, it was not codified and published in such a way that it could battle its way through the obstructions of change of personnel and relegation to the background by matters of more immediate importance.

Before proceeding with a review of actual events, the writer wishes to record what appears to him to have been a sound course to adopt. This is based on the Fuel Oil Board report as summarized in Part II of this history. The only way of assuring accomplishment of this plan would have been its promulgation by the Navy Department for execution by the proper bureaus.

An office should have been established in the Navy Department, directly under the Secretary. An officer of rank and experience should have been placed in charge of this office with proper facilities and adequate personnel, gathered from the excess personnel in the Department. The expenses of the office would have been modest and could probably have been justified to Congress. This office would have formulated the plan for the Secretary's approval; would have kept track of changes in the situation to enable it to modify the plan, as necessary to keep it up-to-date; and would have checked up on the execution of the plan. The establishment of this office would have conformed to recommendations of both the Fuel Oil Board and the Engineer-in-Chief.

Estimates should have been prepared for the cost of studying the reserves and consolidating their control and for settling disputes.

An actual plan should have been drawn up by the Navy Department for the acquisition of a petroleum reserve in Oklahoma or Texas and this concrete plan should have been presented to Congress. Reserves Number 2 and 3 were both of limited naval value and could have been used for exchange purposes.

A specific estimate should have been prepared for the construction of a refinery or topping plant; the support of the leaders in the oil industry for this project should have been sought; and the drive for Congressional approval begun.

Preparation of a definite plan by the general board as to the location and desired rate of construction of 20,000,000 barrels of additional fuel oil storage should have been undertaken. The plan once formulated should have been prosecuted by the Secretary's office until congressional authorization was obtained. The funds should have been requested as necessary.

The tanker situation should have been studied and a plan formulated for making the combatant fleet self-supporting in fuel. Such additional tankers as the refinery and storage system required should have been covered by a separate plan.

The Bureau of Engineering should have been specifically charged with the preparation of fuel oil specifications; and the bureau should have started a continual study of the problem based on the character of the normally supplied fuel oil on the one hand and the needs and equipment of naval vessels on the other.

As a matter of fact, most of the things which should have been done were started; but the lack of definitely formulated and approved plans put the results too much under the influence of current circumstances and changing personnel; and the results attained to 1934 were so incomplete as to place fuel oil at that time in a position which would have constituted a major emergency in the event of war. It is believed that the following review will substantiate this statement.

UTILIZATION.

In general, the question of utilization can be resolved into two parts, (1) gradual improvement and development, and (2) radical innovations or changes.

A great deal of the development work was incidental to other matters. For example, the high cost of fuel oil and the limited appropriations in the years following the war led to much work in the fleet toward improving economy. The principal gain made in this respect was the realization that training of personnel was of primary importance and that this was particularly true of Engineer Officers of destroyers.

In the Fleet no outstanding technological development occurred. Data was obtained on the grades of fuel oil which could be used by various vessels. Tremendous economies were effected merely by more intelligent application of the rules set forth in the Bureau's instructions. These were based very largely on the work of the Fuel Oil Test Plant.

The Fuel Oil Test Plant, the name of which was changed to The Naval Boiler Laboratory in 1932, was under the successive charge of:

Lieutenant Commander W. R. Purnell.....1919-1922
Lieutenant Commander H. H. Norton.....1922-1924
Lieutenant Commander H. G. Donald.....1924-1926
Lieutenant Commander J. S. Evans.....1926-1928
Lieutenant Commander J. J. Broshek.....1928-1930
Lieutenant Commander C. C. Ross.....1930-1931
Lieutenant Commander Lybrand Smith 1931-1933
Lieutenant Commander T. A. Solberg.....1933-1935

Early investigation during this period was closely related to the question of fuel oil quality. The reasons were: the formation of the Pacific Fleet and its transfer to the West Coast required the Bureau of Steam Engineering (changed in 1920 to the Bureau of Engineering) to find out more about the heavier fuels currently available from California; the war specifications developments had indicated a shortage of the higher grade Navy Special Fuel Oil and indicated that the only large assured supply of fuel oil would be in the heavier grades; and the price differential between Bunkers A and C offered a large economy to the Navy if the latter could be used. This matter will be more thoroughly discussed in a later section.

In connection with the appearance of the Pacific Fleet in California waters, the Commander-in-Chief caused a number of reports to be made on the experience of ships in handling and burning California fuel oil. This oil was heavier than the fuel oil to which the fleet had been accustomed. The reports as submitted are very valuable, but deficient in descriptions of the oil as regards viscosity. This was due to the fact that the *Idaho* was the only vessel in the Battle Fleet equipped with a viscosimeter. Where reports of

analysis were furnished by the oil supplier, the report lost its value as soon as the new oil was mixed with other already in the tanks.

Detailed reports were received from the three battleships of the *New Mexico* class and from ten destroyers. The characteristics of the fuel oil used and the general results obtained are summarized below:

U. S. S. *Idaho.* Difficulty was experienced on the final acceptance trials in running smokeless with a California fuel oil of 19 degrees Beaumé and viscosity of 1570 seconds Saybolt at 70 degrees F. and 168 seconds Saybolt at 140 degrees F. Oil was at a temperature of 66 degrees F. with sea water at 55 degrees F. Suction heating coils gave a temperature increase to 76 degrees F. No difficulty in pumping was experienced either with or without heating coils. The full heating capacity gave a maximum oil temperature to burners of 140 degrees F. which was insufficient for smokeless combustion. It was decided to change steam connections to put each pair of parallel heaters in series to increase the temperature.

After the alteration was made, a run was made on 31 October, 1919, using a fuel oil of 19.6 Beaumé and viscosities of 685 seconds Saybolt at 70 degrees F. and 109 seconds at 134 degrees F. This oil was appreciably less viscous than that previously used and no difficulty was encountered with the heaters in series. However, with parallel operation, the oil temperature to the most remote boiler in the fireroom was too low to permit steaming smokeless.

U. S. S. *New Mexico.* On 16 October, 1919, the *New Mexico* made a run with one fire room at full power using a fuel oil of 19.6 degrees Beaumé and a viscosity (reported by the supplier) of 57 Engler at 60 degrees F. This corresponds to about 2200 seconds Saybolt at 60 degrees F. The *New Mexico* had no difficulty in burning this oil at 140 degrees F. Her heaters could have given a much higher temperature had it been desired.

U. S. S. *Mississippi.* The *Mississippi* made a two-hour run with one boiler room at full power using a fuel oil of 19.2 degrees Beaumé and viscosities in Saybolt seconds of 3117 at 70 degrees, 990 at 88 degrees and 183 at 141 degrees F. There was no difficulty at all on this run. The Commander-in-Chief ascribed the

difference between the *Idaho* and *Mississippi* experiences to the atomizers which were Peabody in the case of the *Mississippi* and Schutte and Koerting in the *Idaho*. It was recommended that installation of the latter type of burner be discontinued.

Destroyers. The Commander-in-Chief, on 18 November, 1919, forwarded the result of canvassing destroyers on their experiences with heavy West Coast fuel oil. The reports summarized are as follows:

Destroyer	*Gravity*	*Viscosity*	*Remarks*
Elliott	24.85° Be.	10.8 E. at 70	No difficulty.
Boggs	14.0° Be.	Not given	No pumping difficulty, smoke ascribed to poor personnel.
Williams	20.5° Be.	31.5 E. at 70	No difficulty.
Buchanan	23.2° Be.	113 E. at 70	No difficulty in burning at 120 degrees F. which raises the suspicion that the viscosity was 11.3.
Roper	No data		No difficulty.
Wickes	No data		No difficulty.
Walker	No data		Nothing.
Aaron Ward	No data		Light smoke ascribed to low temperature due to inadequate heater drains.
Chew	No data		

The above data being not very conclusive, additional runs were ordered. The report was submitted on 30 January, 1920. Ten destroyers made the run and all without difficulty in burning. The *Buchanan, McKenzie* and *Crane* were unable to pump satisfactorily until the tank suction heater coils were cut in. The data submitted showed that in every case pumping was satisfactory when the temperature to the heater was 70 degrees F.

Only three destroyers reported viscosities of the oil used. These were:

Buchanan .....290 E. at 60 degrees F.
Elliott .....290 E. at 68 degrees F.
Crane .....433.3 E. at 60 degrees F.

It was reported that pumping was satisfactory with a temperature giving a viscosity of 250 degrees E. and satisfactory smokeless combustion at 11 degrees E. The viscosities were obtained from a curve furnished by the supplier and must be considered as unreliable because of the wide divergence from the experience of the Fuel Oil Test Plant.

Summarizing all of the above reports, it is apparent that little was contributed to the solution of the viscous oil problem. None of the fuel oil tested had a viscosity approaching those of the oils under consideration on the East Coast. It was determined that the West Coast fuel oil being supplied was satisfactory and thereby removed the doubts which may have arisen in connection with West Coast Fuel oil specifications discussed in a later section.

Apparently as a result of the *Idaho* difficulty the Bureau on 21 January, 1920, standardized on but two types of atomizers and registers, the Bureau and the Peabody types. The Schutte Koerting and others were thus eliminated. Both of the two acceptable types had been developed at the Fuel Oil Test Plant.

On 27 June, 1919, the Bureau authorized a test at the Fuel Oil Test Plant using fuel oil of three gravities, 20-21 degrees, 18-19 degrees and 16-17 degrees to determine the limitations of standard Navy fuel oil equipment in the use of these oils; and on 28 June, 1919, authorized a test on behalf of the Shipping Board on the practicability of blending without agitation, heavy Panuco (Mexican) crude and relatively light Pine Island crude. On 11 July, 1919, the Fuel Oil Test Plant submitted an agenda for the heavy oil test. This agenda was approved by the Bureau on 16 July, 1919. The agenda for the Shipping Board test was submitted on 5 August, 1919, and approved on 13 August, by the Bureau.

On 30 September, 1919, a preliminary report on the Shipping Board test was submitted. This report was to the effect that blends of the two oils in question could not be made satisfactorily without agitation but that a very little agitation made a satisfactory and stable blend. Evaporative tests were to be run on the blended oils but no report on the results can be found.

No record can be found of any report having been made on the Bureau test of heavy oils. On 15 October, 1921, the Bureau with-

out reference to its previous letter authorized a test of *burning cheaper fuels,* and, if necessary, development of suitable burners and registers.

A preliminary report on this test of cheaper oils was made on 29 March, 1922. This report stressed the difference in cost between the grades of oil giving the following for delivery at Philadelphia:

Bunker A	$2.65 per barrel
Bunker B	1.73 per barrel
Bunker C	1.36 per barrel

The characteristics in handling were an average temperature for burning of 170 degrees F. for Bunker B and of 235 degrees F. for Bunker C. The cheaper oils were burned satisfactorily after preheating, in a number of standard types of burners.

It was found necessary to heat the Bunker B oil to about 95 degrees F. in order to move it sufficiently for burning 1000 gallons per hour.

It was stated that no reason appeared why any Bunker B oil could not be handled and burned by any vessel which had facilities for heating oil in the tanks to 90 degrees F. It was also recommended that the Bureau make a decision on changing instructions to permit heating fuel oil between heaters and boiler fronts above the flash point. This change would be necessary to permit Bunker C fuel oil to be used.

On 15 April, 1922, Bureau of Engineering Circular letter D-28 changed the existing instructions by the substitution of the following paragraph:

"Heating of Fuel Oil—

"The temperature of fuel oil shall never be raised to or above the flashpoint in any part of the system except that between the heaters and the atomizers; the proper temperature at which the fuel oil shall be delivered to the atomizers is that temperature which reduces the viscosity to between 12 seconds and 18 seconds Saybolt Furol (2 degrees and 4 ;rees Engler). However, in no case shall the fuel oil be heated to a higher temperature than 20 degrees F. below the fire point. Fuel oil in the tank and other parts of the system shall not be heated to a higher temperature than 130 degrees F."

On 13 April, 1922, a letter was sent to the Fleet Commanders requesting a report on the condition of heating coils in fuel oil storage tanks because of the apparent necessity for using more viscous types of fuel than those then in use.

This letter in addition to a large number of answers brought one from the U. S. S. *Maryland* which reported some experimental work on the handling of Bunker C oil.

The *Maryland* reported that no trouble was experienced in pumping these oils if the oil at the pump suction was heated to about 80 degrees F. This temperature was determined in port and to make sure that the temperature could be reached at sea, the heating surface of the coils in two tanks was increased from 7.5 to 15 square feet.

The *Maryland* proceeded to sea with a Bunker C fuel oil having a viscosity of 204 seconds Saybolt Furol at 122 degrees F. No trouble was experienced up to 15 knots with an average oil temperature in the tanks of 50 degrees F. After bunkering with an oil of 321 seconds Saybolt Furol viscosity of 122 degrees F., the *Maryland* made successful runs at 20.5 knots with the following temperature; Oil in tanks 56 degrees F., Oil suction 85 degrees F. and oil to burners 230 degrees F. In raising the speed above 20.5 knots difficulty was encountered in maintaining steady oil pressures at about 21.3 knots.

The concluding paragraph of the *Maryland's* report is quoted as of interest:

"In conclusion two factors which may well be controlling factors should be noted: These are (1) Temperature of oil in the tanks and (2) smoke. With respect to factor (1) the lowest tank temperature with which the *Maryland* had to deal was 48 degrees F. What effect a lower tank temperature—controlled by external water temperatures—would have in burning low grade, high gravity oil is problematic. However, the experience and opinion of the *Maryland* would indicate that a large heating surface, better designed tank coils built around the end of the high suction pipe like a coiled helical spring, would answer this phase of the problem.—With respect to factor (2) Smoke—Grade C oil unquestionably requires a higher trained personnel and a higher degree of vigilance at the boilers, control room and bridge smoke

indicators station than were obtained when burning grade A oil. This care and watchfulness has been closely realized in 3 months' experience. However at the higher powers the solid and incombustible matter in suspension in grade C oil will cause smoke and the deposit of ash on deck, no matter how highly trained the personnel. This problem of course will be answered by installation of centrifuges with which it is understood the Bureau is now experimenting."

One fact which should be recorded in any history of fuel oil development in the Navy is the retirement of Rear Admiral R. S. Griffin, U. S. N., as Engineer-in-Chief on 22 September, 1921. In his eight and one half years incumbency Admiral Griffin probably earned more credit for fuel oil development than any other individual. He had instigated the Halligan Board, had fought for retention of the Reserves intact and for adequate storage tank construction and had exerted every effort to maintain the quality of the Navy's fuel oil. His reports and official recommendations show him to have been fully cognizant of the military importance of the quality of fuel oil as well as of the logistic and engineering requirements.

Admiral Griffin's successor, Rear Admiral J. K. Robison, U. S. N., entered office when the question of economy was at its height. The development of the fleet to permit the use of the cheapest fuel available was apparently a highly desirable thing and the new Engineer-in-Chief stressed this very highly. The result was a period of forced development which was replete with lessons for future engineers. The three outstanding technological changes which occupy important space in the records are discussed below.

Fuel Oil Centrifuges. This project, mentioned in the *Maryland's* report was intended to permit vessels to remove water and sediment from fuel before burning, thus permitting the use of cheaper fuel oil. Centrifuges were tested at the Experiment Station and the Fuel Oil Test Plant and reported as satisfactory.

The Engineer-in-Chief reported that after successful tests at the Experiment Station using funds which were made available by economies practiced in the fleet, plans were perfected in 1921 for the installation of fuel oil separators in ten ships. The equipment was purchased and in some cases installed. On at least one ship,

the *Idaho,* money never became available for the installation and the vessel entered the Navy Yard for modernization in 1931 with the separators uninstalled. The experience of the ships in which the installation was completed was such that in 1932 the Bureau of Engineering decided to discontinue fuel oil separators. During the ten years which this project lived, it was announced authoritatively from time to time that separators would be used to permit utilization of cheaper fuel oils and yet at no time was more than 5 per cent of the fleet equipped.

The probable reason for the failure of this project was the submergence and loss of the main intent of the plan. Centrifuges were originally intended to remove undesirable constituents from the cheapest grades of fuel oil which could then be satisfactorily burned. Their only use, except in isolated cases, until it should become possible by reason of a 100 per cent fleet alteration to bunker the cheaper grades of fuel oil, was in removing water which might get into the oil.

Reports from ships showed that the use of centrifugal separators for this purpose was bothersome and little more effective than gravity settling. With the passage by Congress in 1924 of legislation which provided very severe penalties for the pollution of harbors and coastal waters the principal question became one of oil in water rather than of water in oil and the matter passed to the Bureau of Construction and Repair which had cognizance of disposal of bilge and other waste waters. At first it was planned to use the Engineering separators for oil-freeing bilge water. When the Bureau of Engineering reached the conclusion that separators were of no value in removing water from oil and had forgotten the original intent, centrifugal separators for fuel oil were omitted as an engineering requirement and became the exclusive property of Construction and Repair.

For the purpose of fitting the fleet to burn the cheapest grades of fuel oil, centrifugal purifiers were discarded without a real service test.

Blower Burners. In 1922, Commander H. H. Norton, officer in charge of the Fuel Oil Testing Plant, designed and built a blower burner. It combined all the equipment necessary for burning oil at the furnace with the forced draft blowers in one assembly on the

furnace front. The original experiments were so successful that a service test installation was made on the U. S. S. *Williamson* on 1 September, 1922. The burner was used both in port and underway and was again highly satisfactory. In 1923, when it was decided to reboiler the President's yacht, U. S. S. *Mayflower,* and change her to an oil burner, blower burners were specified and no forced draft blowers were included in the design. Starting at about the same time it was decided to equip all ships with blower burners for port use and lower powers underway. Of course the ships would retain their forced draft blowers for higher powers.

One limitation of this equipment which had not been foreseen showed up on the earlier tests. That was that, as the amount of oil burned per hour increased, the pressure inside the furnace increased until it became greater than that in the fireroom. It was found impossible to make casings gas tight so the boilers had to be operated at rates low enough to insure a pressure in the fireroom positive to that in the furnace. Until this fact became apparent some engineers considered that the blower burner would be adaptable to all ships for all powers.

In his report for 1925 the Engineer-in-Chief reported that a portion of a $1,500,000 appropriation for making improvements in machinery had been expended for fitting vessels with individual blower burners for the more economical burning of oil. On 1 March, 1926, the Engineering Bulletin carried a notice that the installation of blower burners on combatant ships had been discontinued pending further experience. The death knell of a second project had sounded. No installations were made subsequently and the blower burner was removed entirely from the Machinery Specifications in 1933.

The blower burner was not projected as a means of using cheaper oil but of burning less of any kind of oil for a specific service. The tests at the Fuel Oil Test Plant had indicated a saving of fuel of from 15 to 30 per cent. Since the greatest part of the Fleet's steaming is in port or at reduced powers, a complete installation of blower burners should have resulted in at least a 15 per cent reduction in the annual fuel oil bill.

The conversion had come as close to completion as any other similar project ever had. All types of ships were fitted with either

a complete battery of blower burners or enough for steaming at the maximum rate permitted by furnace pressure without the use of forced draft blowers. Many mechanical difficulties arose. The original impellers proved weak and caused a number of casualties. In general the boiler fronts proved too weak to support the burners and reports of sagging and warping were numerous. The locations selected for the two burners in each destroyer were the two upper openings which proved bad because the wider flame of the blower burner impinged on the tubes and caused smoke difficulties which could be remedied only by running the main blowers. Most ships which reported showed no, or a very small, gain in efficiency in the use of blower burners. The destroyers reported that the use of a small electric blower, installed by some ships was much simpler and far more efficient.

It seems probable, in view of the very excellent reports received originally both from the Fuel Oil Test Plant and the first installation afloat, that had the forces afloat been better instructed and more willing to cooperate in the development of the new device and had the personnel in the Bureau of Engineering remained unchanged and as sure of the blower burner as it had been, eventual success might have been obtained. However, such was not the case, the two million or more dollar investment was scrapped, and another one of installing electric forced draft blowers for port use and cruising at reduced powers was undertaken.

Recirculating System. Investigations authorized at the Fuel Oil Test Plant on the possibility of using more viscous fuel oil have been mentioned. The recirculating system grew out of these investigations. The following quotation from Admiral Robison's annual report for 1922 can be used for introducing this section.

" Progress toward the general use of bunker 'C', the heaviest and most viscous grade of fuel oil, has been made. Certain vessels which formerly used a lighter grade are now successfully using bunker 'C'. Certain changes have been made to permit heating this grade of oil in the system to a higher temperature in order that it may be lessened in viscosity and therefore be adopted to handling by pump.

"In view of the higher thermal value per pound (NOTE—correctly quoted but should have been per gallon or per barrel) of bunker 'C' and its decreased cost per barrel as compared with the lighter grades of fuel oil, the bureau has in prosecution a plan whereby eventually all ships of the Navy will be enabled to burn this heavier grade of fuel oil. Such a drastic change can not be made within the compass of one year and will require the expenditure of an appreciable amount of money, which, due to the reduction in Naval appropriations for 1922 and 1923, will have to be obtained through reductions for expenditures in other directions throughout the naval service. It is hoped, however, that during the year 1923 such changes as are necessary in the material equipment of ships may be made which will result in decreased fuel expenditures, as well as secure availability for naval use of any grade of fuel oil."

The following year's report stated.

"The bureau has conducted experiments at the Fuel-Oil Testing Plant on a system for recirculating fuel oil in ship's bunker with a view to determining the practicability of using heavy viscous fuel oils in the oil-burning apparatus of naval vessels. On the results obtained, installation of recirculating apparatus has been made on several ships for service test."

And in 1928, Admiral Halligan, Engineer-in-Chief reported:

"Fuel Oil recirculating systems aboard ships have been superseded by coils for direct heating of fuel oil in storage tanks. This change has resulted in simplifying the fuel-oil piping in the machinery spaces and reducing the weight of piping and auxiliaries required."

The events in connection with the rise and fall of the recirculating system were typical of the period. Development of the system was rushed through with special tests at the Fuel Oil Test Plant. These tests superseded the "cheap fuel" tests and brought them to an end. Tanks representing certain ones on the *Maryland* were fitted up and a preliminary report was rushed through to permit rapid design of an installation on the *Maryland*. The tests indicated that fuel oil in the tanks could be heated by pumping out

through a heater and then back to the tank. The equipment required was extremely heavy but this was accepted even in the face of the recently approved Washington treaty.

The *Maryland* was the only vessel completed and in commission on which the recirculating system was installed. Specifications of ships under construction were changed to provide for recirculating systems on the following vessels:

Battleships—*West Virginia.*
Airplane Carriers—*Lexington* and *Saratoga.*
Light Cruisers—*Raleigh, Marblehead, Trenton* and *Memphis.*

The other six light cruisers were too far along to permit the change. When the battleship modernization program was instituted, recirculating systems were installed in the *Utah, Florida, Arkansas, Wyoming, New York* and *Texas.* The first of the heavy cruisers, the *Pensacola* and *Salt Lake City* were laid down under the 1925 General Specification which required recirculating systems. So also was the modernization of the *Oklahoma* and *Nevada.* When the decision was reached to replace the recirculating system with direct heating in tanks, an effort was made to modify current construction. This effort was successful in the case of the battleships but the cruisers had progressed too far and had to be completed with the heavy cumbersome system.

The first installations after the change consisted of a large number of helical pipe coils distributed through the tanks. This practice was superseded by a simpler arrangement of straight pipes connected together by return bends.

Although the Engineer-in-Chief had indicated in his annual report that the plan contemplated altering every ship in the Navy to permit the use of bunker "C", when the recirculating system proved to be undesirably heavy and complicated, and the simpler heating coils were adopted, apparently the plan to extend the improvement to all vessels was dropped. The total accomplishment can be summarized as follows as regards the Fleet in 1934:

Battleships—15
5 Recirculating Systems
7 Large Heating Coils (Modernization)
3 Small Suction Heating Coils

Light Cruisers—10
4 Recirculating Systems
6 Small Suction Heating Coils
Heavy Cruisers—10
2 Recirculating Systems
8 Large Heating Coils
Destroyers—229
229 Small Suction Heating Coils

It is apparent that 238 combatant vessels out of a total of 264 were still not equipped to handle the most viscous and cheapest grades of fuel oil.

While the above described radical improvements were occupying the center of the stage and consuming a great deal of money and effort, a real and effective development was more quietly underway. It would be valuable to describe a number of Fuel Oil Test Plant investigations in detail but inasmuch as many of them have already been published in Engineering Bulletins and the results of the most important ones can be found in the Boiler Chapter of the Manual of Engineering Instructions, these will be omitted. The excellent character of the material in the manual is indicative of the valuable and excellent work of the Fuel Oil Test Plant.

One test which was made will be mentioned because of its possible future value in connection with the elimination of the fuel oil heater fouling difficulty described below. This was the test of the Ray rotary burner which obtains atomization by the centrifugal force applied to the oil by throwing particles from the rim of a rapidly revolving cap. The burner was successful in atomizing oil of very high viscosities, with reasonable efficiency and smokeless combustion. It was considered too large and complicated for general adoption but many engineers familiar with this type of burner considered that it could be developed for naval use. The desirable advantage of the rotary cup burner over any of the pressure mechanical atomizers is that preheating is not essential and fuel oil which is sufficiently fluid to permit pumping can be satisfactorily burned.

The fuel oil heaters used by the Navy have always been of the shell and tube type. In a few cases the oil to be heated is passed

around the tubes which contain the heating steam. In the most common type the oil passes through the tubes with steam surrounding them in the shell.

In designing an adequate service heater, the two principal factors are steam pressure (temperature) and heating surface. Since higher temperatures permit the use of a smaller heating surface with consequently lighter and smaller heaters, the Bureau of Engineering had always specified that steam at full boiler pressure be used for full power. Since steam pressures have progressively increased, the temperatures to which fuel oil in passing through heaters have been subjected have likewise increased.

Heater fouling has always been an operating problem. Growth of a hard carbon-like deposit on the oil side of the tubes has always been experienced. This has necessitated that tubes be cleaned or replaced every two to three years. Some cleaning by removing any deposit except the hard carbon had been prescribed as a routine by boiling out the heaters with kerosene. Such was the status of fuel oil heater fouling when in 1931 the *Colorado* reported the first serious difficulty. This vessel found itself in the embarrassing position of being unable to keep up with the fleet on its return from the concentration in Southern waters. The difficulty, at first ascribed to a foul bottom was eventually reduced to about one-third foul bottom and two-thirds dirty fuel oil heaters.

That casualty appears to have been the first to call the Bureau of Engineering's attention to the fact that it would not be safe to continue to design and install fuel oil heaters casually. The *Colorado's* difficulty arose principally from the fact that she had only four large heaters to serve eight boilers and that these heaters were so installed, behind piping and voice tubes, that it was a four day job to take one down and clean it. The natural disinclination to perform such a job, not recognized as a necessary routine, and the impossibility of doing it during a period of heavy fleet operations, had permitted a supply of cracked oil to materially reduce the military value of one battleship. Since there was no general similar difficulty throughout the fleet at the same time, it appears that even though the fuel oil used contributed, the principal difficulty could be ascribed to the installation.

In trying to clean out the heaters as a rush job preparatory to Fleet operations, the *Colorado* tried boiling out with carbon tetrachloride, a reputable solvent. The result was that a hard formation was built up in the tubes, completely plugging them. The vessel maintained its schedule only by obtaining a supply of Diesel fuel oil which could be burned without preheating. The *Colorado's* difficulties had hardly been cleared up when reports of general difficulties of a similar nature began to come in. A new fiscal year had started and the troublesome fuel oil was coming from a different source. The fuel oil which, quite definitely, was responsible for excessive deposits in fuel oil heaters was composed of a cracking still residuum blended with a sufficient quantity of a more fluid oil to bring the product within the viscosity limitations of the specifications.

The major portion of this particular occurrence properly belongs under the head of "Quality." The effect on equipment did not become definite immediately, but, with the question brought to the fore, the Bureau of Engineering, in 1933, undertook investigations of fuel oil heater design; methods of cleaning fuel oil heaters; and high viscosity atomizers of the various types. No definite results of these tests were attained prior to the end of the period here discussed.

One very practical result was obtained early in the investigations by the Naval Boiler Laboratory. This is in connection with the fouling of fuel oil heaters. After studying all of its former reports and all available data both from these reports and more recent work, the laboratory found that, although there appeared to be an optimum atomizing viscosity for fuel oil, the optimum point was not sharp and the curve of efficiency versus viscosity was fairly flat at the top. The laboratory realized that if fuel oil was burned on this curve toward the high viscosity side of the optimum but within about two per cent of the maximum efficiency, the fuel oil heater temperatures required would be materially reduced. The sacrifice of one or two per cent in efficiency would be more than offset by the probably greater freedom from heater difficulty. This information with instructions in the premises was promulgated to the forces afloat.

At the beginning of 1935, the Navy was very much aware that the UTILIZATION of fuel oil was very closely tied up with its QUALITY. It was also apparent that accelerated development was essential to obviate future possible difficulties. A very comprehensive investigation was underway.

SILVER BRAZING ALLOYS IN THE MARINE FIELD.

By Robert H. Leach, Member,* and Leo Edelson, Member.†

The use of silver alloys for joining metals has shown a large increase in recent years, and this development has taken place in spite of the great improvements that have been made in welding and brazing processes in which base metals or their alloys are used. These alloys have been called silver solders and classed as hard solders to differentiate them from the common lead tin alloys which are used extensively. It is believed, however, that "silver brazing alloys" is a more descriptive term to use and indicates more definitely the temperatures at which they melt and the type of joint made with them.

The following definition is suggested:

Silver Alloy Brazing—*A method of joining metals by means of heat, wherein the filler metal is a silver alloy with a melting point above 1000 degrees F., but lower than those of the metals or alloys to be joined.*

These alloys are not new and have been used for many years by silversmiths and coppersmiths and also, to a limited extent, for such purposes as joining band saws and other applications where strong ductile joints were required. However, there has been an increasing demand for better methods of joining metals and alloys which are used in different types of modern construction and the manufacture of many products. In many cases, soft solder failed to provide the requisite strength and resistance to corrosion at either normal or elevated temperatures, and brazing with base metal alloys did not solve the problem satisfactorily because of the high temperature necessary to melt them. Silver brazing alloys melt at temperatures from 1175 degrees F. to 1600 degrees F. as

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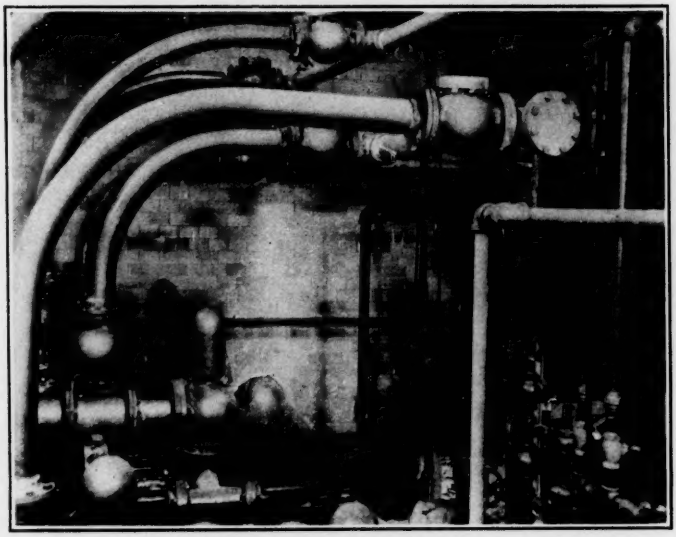
Silver Alloy Brazed Fittings.



Silver Alloy Brazed Flanges.

compared with base metal alloys melting from 1600 degrees F. to 1900 degrees F. and produce strong malleable joints which resist shock, vibration and corrosion; thus providing a medium for joining both ferrous and non-ferrous metals and alloys with prevention of damage from over-heating.

Although the Navy Department had adopted certain standard alloys there was not much information available to engineers in regard to the physical properties of these alloys and the relative merits of different compositions. In 1926 a committee was formed in the American Society for Testing Materials to investigate these alloys and recommend standard compositions. The work was confined chiefly to the silver-copper-zinc alloys but the effect of other metals was considered. This work resulted in the final adoption in 1929 of ASTM standard B-73-28T for silver solders. An appendix to the specifications gives brief general information on the compositions selected and in June, 1930 [1] a paper was presented at the annual meeting discussing more fully the properties of silver solders and proper methods for use. Since then other publications have appeared and a list of some of them is appended to this paper. Although the standard ASTM alloys may be used for the majority of brazing problems, other proprietary silver brazing alloys have been developed and are used extensively in the industrial fields because of their special properties.

The high standards and requirements in the better types of marine construction have accounted for the use of silver brazing alloys in this field for a long time. One of the older and well known uses has been for joining turbine blades to packing pieces and the shrouding and lacing wires to some types of marine turbines. The largest single use of these alloys in marine construction has been their application to ship's piping. This use covers the slip or soldered fitting type of joint and more recently the joining of copper and copper nickel alloy tubing to composition flanges and copper nickel alloy flanges which are rapidly replacing the old type of brazed flange. Another use is for joining ferrous sleeves on non-ferrous piping at point of attachment to decks and bulkheads. Two excellent papers [2 & 3] by Mason S. Noyes have been printed in the JOURNAL describing several of the investigations and tests that

were conducted to determine the merits of these alloys for joining pipes and fittings.

Following their adoption for certain classes of piping construction, simply worded but thorough instructions [4] were drawn up and distributed to the men at the construction yards. Arrangements were also made for trained men to visit the yards and instruct in the proper manner to make satisfactory joints and it is understood that this cooperation with the personnel at the yards has produced most gratifying results.

Some other uses in the marine field are: in the manufacture of electrical equipment, x-ray equipment, surgical and dental apparatus, air conditioning and refrigerating systems, unit heaters, oil centrifuges, tanks, oil and gas lines.

Experience has shown that there are many important factors in the application of these alloys that greatly affect the results obtained. A more specific discussion of different types of joints and procedures for making them follows:

Selecting the Grade of Brazing Alloy.

There are five grades of silver brazing alloys approved for Naval Construction that are listed in the Navy Department Specification leaflet 47S13-C. Grades O, I, II are silver-copper-zinc alloys with flow points of 1500 degrees F., 1370 degrees F. and 1325 degrees F. respectively. Grade III contains silver-copper and phosphorus, flows at 1300 degrees F. and should only be used on copper, brass and non-ferrous metals and alloys. Grade IV flows at 1175 degrees F. and when used with silver brazing flux Navy Specification 51F4, the low melting point gives a wider margin of safety against damage to metals and alloys from overheating. The leaflet gives the compositions and suggests the different applications for which each grade is considered to be most suitable. It does not seem necessary to attempt further discussion except to say that although there may appear to be certain savings in the use of the lower grade solders with higher melting points, because of their lower cost, a complete analysis of all the cost factors will frequently show that the total cost of the finished joint will be less when the lower melting point alloys are used:

Design of Joint.

Silver brazing alloys should not be used as fillers or on V joints. They flow freely into narrow openings and the strongest joints are obtained by using small clearances. It is therefore most important that proper attention be given to the design of the joint. Figure 1 illustrates a few of the common types of joints.

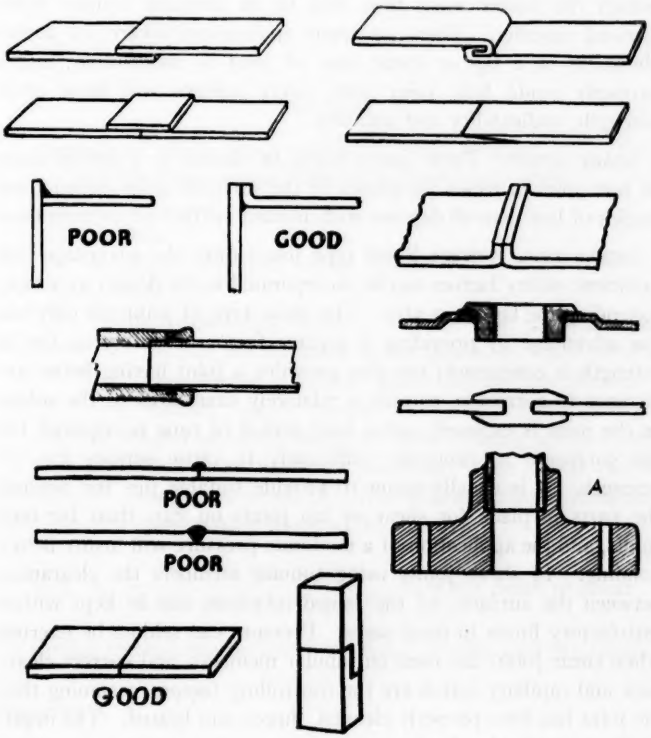


Figure 1.

There are three types of joints: butt, scarf and shear; and the shapes of the members to be joined may be generally classed as flats, rounds and tubular.

BUTT JOINTS: A great number of butt joints are produced every year in industry which give excellent service under all the conditions to which they are subjected. To insure the maximum strength in butt joints, the surfaces should be cut or machined square and even; so that with suitable jigs all parts of the surfaces between which the solder must flow will be in intimate contact when pressed together. There are many applications where the double thickness of a lap or shear type of joint is undesirable; and a properly made butt joint with silver solders will have great strength, malleability and ductility.

SCARF JOINTS: These joints might be classed as a special form of butt joint in which the planes of the surfaces to be joined form angles of less than 90 degrees with another surface of the members.

SHEAR TYPE JOINTS: Shear type joints offer the advantage that sufficient safety factors can be incorporated in the design by simply extending the lap shear area. The shear type of joint not only has the advantage of providing a greater factor of safety as far as strength is concerned; but also provides a joint having better resistance to corrosion, as only a relatively small area of the solder in the joint is exposed, and a long period of time is required for the corrosion to penetrate sufficiently to cause serious loss of strength. It is usually easier to provide suitable jigs for holding the parts in place for shear or lap joints on flats than for butt joints, and the application of a moderate pressure will insure better bonding. In shear joints using tubular members the clearances between the surfaces of the joined members can be kept within satisfactory limits in most cases. Pressure can seldom be exerted when shear joints are used on tubular members, and correct clearance and capillary action are the controlling factors, assuming that the joint has been properly cleaned, fluxed and heated. The depth of shear required will of course vary according to the strength of the metal and the factor of safety that the engineer believes necessary to provide. The following formula and example are given as illustrating one method of figuring these shear depths.

FORMULA

X = (unknown) = depth of shear
D = shear diameter
T = Tensile strength of weakest member
W = Wall thickness of weakest member
Y = Factor of Safety
L = Shear strength of silver brazing alloy
π = 3.1416

$$X = \frac{YTW}{L\pi D}$$

EXAMPLE

Length of sheer depth necessary when forming 3/4—0.064 wall thickness copper tube to 3/4 steel tube sheets.

X = unknown
D = 0.75
T = 33,000 annealed value copper
W = 0.065
Y = 10. (note: this value is used on this particular job in that the thickness of the tube sheet lends itself to this factor. Where shear depths are limited a smaller safety factor will prove satisfactory)
L = 25,000 psi shear value of silver brazing alloy. (note: this is an arbitrary minimum value which can be expected from all silver brazing alloys containing appreciable amounts of silver.)

$$X = \frac{10 \times 33{,}000 \times 0.65}{25{,}000 \times 3.1416 \times 0.065} = 0.363 \text{ depth of shear}$$

A similar method can be used with flats. In this case the formula becomes $X = \frac{YTW}{L}$

Example: Length of shear necessary when joining 0.050 inch annealed monel metal sheet to a stronger material, or material of equal strength.

X = unknown
T = 70,000 psi (annealed monel metal sheet)
W = 0.050 inch
Y = 4
L = 25,000 psi (note: this is an arbitrary minimum value which can be expected from all silver brazing alloys containing appreciable amounts of silver.)

$$X = \frac{4 \times 70{,}000 \times 0.050 \text{ inch}}{25{,}000} = 0.56 \text{ inch} — \text{length of shear}$$

TABLE I.

RELATIVE STRENGTH OF BUTT AND LAP JOINTS

Grade IV Solder Joints on 0.080 inch × 1/2 inch Everdur Strip

No.	*Type of Joint*	*Tensile Strength Lbs. per Sq. In.*	*Elongation Per Cent in 2 Inches*
	Stock as received	60,900	51.5
1	3/8 inch lap	57,400	43.7
2	1/4 inch lap	56,200	43.7
3	3/16 inch lap	56,900	50.0
4	1/8 inch lap	57,300	50.0
5	3/32 inch lap	57,200	50.0
6	Butt	57,200	50.0
7	Butt	55,600	39.0
8	Butt	57,500	39.0

The figures given in Table I were obtained from tests made to determine the width of lap or shear necessary to provide a joint of equal strength to the Everdur. All of the specimens from No. 1 to No. 6 inclusive broke in the Everdur, outside of the joint. These tests showed that the smallest lap that it was practical to make was stronger than the parent metal. It should be noted, however, that in making these specimens, a light pressure was applied to insure close contact between the joint surfaces in both the lap and butt joints. It would appear, therefore, that when proper conditions can be provided the lap or shear area required corresponds closely with the cross section

area of a butt joint. Another way of stating this would be to say that, if we could obtain in practice the same degree of bonding for the entire shear area as shown in the tests on Everdur, we would be justified in using a much higher figure than 25,000 pounds per square inch as the shear strength for silver brazing alloys. The pressure which may be applied to shear joints on flats undoubtedly accounts to a considerable degree, for their greater strength as compared with those on tubular members.

RELATION OF METAL THICKNESSES: Recognition and careful consideration by the designer should be given to the heating operations necessary in making the different types of joints. For example: with the old type of pipe flange it was necessary to heat the whole mass in order to get the unit hot enough for the brazing alloy to flow. The flange was redesigned by extending the hub sufficiently to provide the necessary depth of shear for the pipe. It was then only necessary to heat this hub which constituted about 20 per cent of the weight of the mass that required heating with the old style flange. Joint "A" in Figure 1 illustrates this improved type of flange.

DISSIMILAR METALS: Silver brazing alloys are used extensively for joining dissimilar metals, and when designing comparatively large units it is necessary to consider the expansion and contraction which will occur in heating and cooling operations. This is usually not an important point in small units that can be evenly heated, but becomes of considerable importance where large masses of metals are involved.

SIZE AND FORM OF BRAZING ALLOY AND ITS RELATION TO DESIGN: One of the characteristics of any silver solder is that it can be produced in all sizes of wire and thicknesses of sheet, as well as in fine filings or powder. The engineer, therefore, has a wide range of form and size which will enable him to select the most suitable for any particular type of joint. There are three general methods of applying these brazing alloys:

1. hand feeding.
2. preplacing the brazing alloy either in or around the joint.
3. providing a groove or reservoir in which the alloy is placed before assembling.

The designer has no particular interest in the size or form of the solder used on those types of joints where the alloys are hand fed. However, this should be of interest to the workman because the size of the wire or strip should be in such proportion to the size of the joint that it will melt quickly and at the same time give sufficient alloy without requiring too great length of wire or strip.

When flat stock is to be joined and the alloys are to be preplaced, the following method of applications may be used:

(a) inserts of thin sheet stock and flat washers
(b) rings of round or other shapes of wire
(c) brazing alloys may be sprayed on the surface
(d) filed or powdered brazing alloys
(e) "tinned" with the brazing alloy by dipping or other methods of application.

The method of heating is an important factor when considering the best method of applying the alloys. When parts are heated in furnaces or chemical baths, it is necessary to preplace these alloys. When heated in other ways there is a choice of either hand feeding or preplacing. The term reservoir type of preplaced alloys refers to those designs in which a groove is cut in one of the members and the brazing alloy is placed in this groove before assembling. This method is used principally with tubular joints. The location, size and shape of the groove will depend upon the size of the members and the design of the completed assembly. Figure 2 illustrates two common methods of using this reservoir type of preplacing the alloy.

If the alloy is placed at (a) the assembly must be heated so that the flow will be vertically downward. If it is placed at "b" the heating may be done in any position. A possible objection to placing the alloy at (a) is that an open space will be left as the solder flows into the joint. The depth of this annular space after the joint is made will depend upon excess of solder which is provided in proportion to the size of the groove. This difficulty can be overcome to some extent by using an insert that not only fills the groove but projects above the surface and as the molten alloy flows into the joint the upper portion of the insert will fill

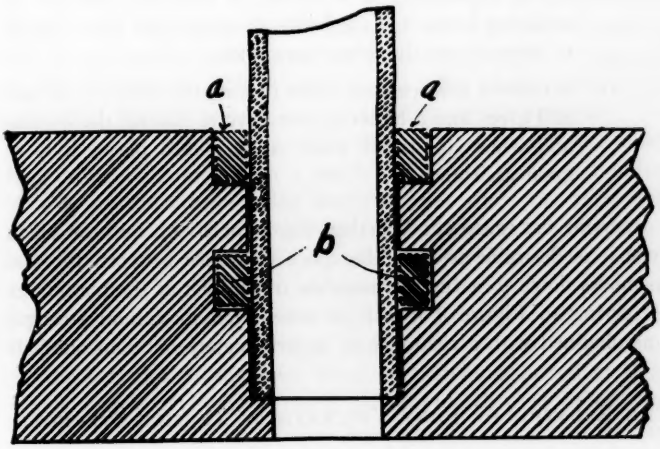


FIGURE 2.

the groove. In either case the depth of the shear area, exclusive of the depth of the groove, should provide a sufficient factor of safety to meet any given requirement for strength. To the extent that excess alloy is provided for filling the groove at (a) one might be justified in considering this as part of the shear area but a more conservative basis would be to consider only the closely fitted part of the joint.

The preplacing of brazing alloys has many definite advantages, both in the flats and in the tubular type of joint, some of which are as follows:

(a) controlled cost per joint unit, without any subsequent waste or loss of alloy, is assured.

(b) where materials are preplaced over the entire joint surface they usually insure the wetting of the total joint areas.

(c) where loaded joints are heated by manual methods, the melting of the alloy is a definite indication of proper brazing temperatures in the work and acts as a temperature control.

(d) where appearance is a factor, it aids the operator in attaining better looking joints, because there is no run off of alloy to mar the joint appearance.

(e) it relieves the operator from feeding the alloy to the unit and gives him a better opportunity to control the heating and where joints are made in restricted places it is of great assistance.

FITTING CLEARANCES: Whether the joint is of butt or shear type it is desirable to hold the space clearance between the two members down to a few thousandths of an inch at the maximum. Referring to Figure 3 it will be noted that maximum strength was obtained with a clearance of approximately one and one-half

THE RELATION OF JOINT THICKNESS TO TENSILE STRENGTH.

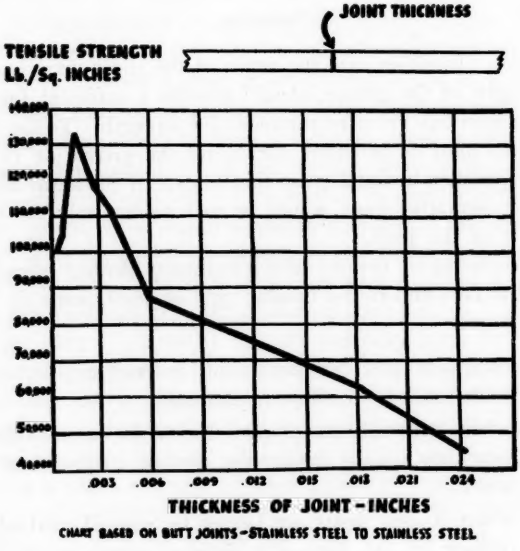


FIGURE 3.

thousandths, and this we believe is generally true of silver brazed joints. The brazing alloy used in these tests was Navy Grade IV which in annealed wire form has a tensile strength of approximately 65,000 pounds per square inch. The 18-8 stainless steel had about 160,000 pounds per square inch tensile strength. The series of butt joints upon which Figure 3 is based were made by heating the joints with a torch sufficiently to allow the free flowing of the brazing alloy into the joint when the alloy wire was brought under the torch flame. The dropping off in strength below one and one-half thousandths is apparently accounted for by bare areas on the joint surfaces. In making the joints with the smallest clearances the members were pressed together during heating and it seems logical to assume that due to irregularities of the surfaces of the joint these bare spots occurred at those points where the surfaces were pressed together so tightly that the brazing alloy could not flow between them. Even when care is taken to provide flat surfaces there may be some variation and, unless the brazing alloy is preplaced in the joint, it is necessary to provide sufficient clearance to insure the free flowing of the brazing alloy over all parts of the joint surfaces. Clearance should be such that there will be sufficient thickness of the brazing alloy film in the finished joint to take care of any irregularities in the joint surfaces, but the thickness of this film should not exceed three thousandths of an inch and should preferably be less if the strongest joints are to be obtained.

Theoretically when thin inserts of brazing alloy are preplaced in the joint it should be possible to prevent bare spots by proper regulation of heat and pressure. In those cases where lap joints on flats are made with preplaced inserts and the pressures are sufficient to overcome any unevenness of the joint surfaces it seems reasonable to assume that the ideal joint would be one in which all excess alloy had been squeezed out and practically none of the original brazing alloy could be found in the finished joint.

In tubular members including those 2 inches in diameter, clearance spaces between one and three thousandths appear to be workable for pipes and fittings. The clearance space in parts of the joint will run as high as .008 in large diameter pipes and fittings, but at other parts of the circumference it will be found that the

fit is comparatively close. Maintenance of proper clearances makes the capillary force more effective and assists in drawing the brazing alloy between the joint surfaces. Experience has also shown that when clearances are small there is less tendency for gas pockets and inclusions.

Figure 4 is a photomicrograph made of a joint having an actual clearance of approximately one and one-half thousandths. It will be noted on examination that there is some indication of alloying; and it is believed that, even in those cases where steels are bonded, there is some diffusion although it may be only of molecular proportion and difficult to observe by microscopic examination.

In concluding the discussion on clearances we should like to emphasize the point that in whatever form the solder is applied before heating, it has the cast structure of an alloy after the joint has been made; and experience has indicated that the thinner this casting, the stronger the joint will be.

Brazing Procedures for Silver Alloys.

CLEANING: Experience has shown that it is difficult to put too much emphasis on the necessity for properly cleaning the surfaces that are to be joined. Either chemical or mechanical methods may be employed. All grease, oil, oxide, scale and dirt should be removed.

CHEMICAL CLEANING: Grease may be removed by many of the reliable chemicals that are available. If oxide or scale is removed by acid dipping the parts should be rinsed well and dried quickly. Chemical cleaning is probably more common in plants arranged for handling a large number of units. Mechanical cleaning can be made effective, but it is suggested that all grease and oil be removed by a piece of clean waste or cloth and then the surface cleaned or scoured with fine emery cloth. Ordinary sheet metal as received from the mills is not sufficiently clean; it is very easy to demonstrate this by attempting to brush some flux on the surface which may appear to be clean and notice how difficult it is to spread and how it pulls together in small areas, leaving large bare spots. If the surface is cleaned with a fine emery cloth this tendency to bare spots will be found to diminish.

3/4" copper tubing soldered with Sil-Fos into a brass "T".

FIGURE 4.

FLUX AND FLUXING: A large amount of space might be devoted to the discussion on fluxes but briefly the three functions of a flux are as follows: to prevent oxidation, dissolve oxides which may be formed, and assist in the flowing of the solder or brazing alloy. Although the last named function is very indefinite it is believed that the flux may have an effect on surface tension or the prevention of absorbed gas films on the surface of the metals to be joined. Evidence is at hand indicating that it does assist even in cases where the brazing is done in a reducing atmosphere and all oxides have been removed.

Brushing a thin paste over the surface is usually the best method for applying the flux. It can be used in dry form by sprinkling along the joint. In some cases hot saturated solutions are used in which the metal can be dipped, but this method is apt to leave irregular bare spots on the surface. It is most important that the surfaces be protected with flux before heating to a point where oxides are likely to form. The flux must not only be fluid at the brazing temperature but it must be chemically active in order that all oxides will be thoroughly removed and thus provide clean nascent surfaces with which the brazing alloy will unite.

The flux given in Navy Specification 51F4 should be used with stainless steels and other metals or alloys which have particularly refractory oxides. This flux begins to melt and become active at 800 degrees F. and is extremely fluid and active at 1100 degrees F. which is the reason that it is recommended for use with Grade IV alloy which flows at 1175 degrees F. This is also an excellent flux to use with other grades of silver brazing alloys because it is stable up to 1600 degrees F. When the heating is done by a torch the direct exposure of the flux to the high temperature of the torch flame may cause some fuming although the temperature of the metals to be joined may be considerably below 1600 degrees F. By constantly moving the torch, however, this superheating of the flux can be minimized; and in all torch brazing it is recommended that either the torch or the members to be brazed should be kept in motion.

It is sometimes thought that the use of a flux eliminates the necessity of cleaning the surfaces but this is not so. The sur-

faces to be joined should be thoroughly cleaned before any flux is applied.

The brazing alloy should also be protected with flux as oxides will form on its surface as well as on the surfaces of the joint.

The removal of the flux after the joint is made is a point that often causes considerable difficulty when certain types of fluxes are used. An advantage of this low melting flux is the ease with which it can be removed by hot water. One simple way of removing the flux is to apply water to the joint as soon as the brazing alloy has solidified, and the heat in the joint is effective in assisting the removal of the flux. If water cannot be applied to the joint before it is cooled the assemblies can be immersed in hot water; and the addition of a small amount of acid to the hot solution will assist in dissolving the flux. Any flux remaining on the joint after it is made should be removed in order to prevent corrosion which may take place even though the flux itself is neutral because of the hygroscopic character of these fluxes and their tendency to absorb moisture which in combination with the oxygen in the air may have a corrosive effect on the metal.

Borax and boric acid may be used for brazing purposes. Borax is a thin fluid at 1400 degrees F. but begins to thicken as the temperature decreases. The bubbling which is observed when ordinary borax is heated is due to the water of crystallization which is driven off. Fused borax is used to avoid this. When water is used to make a paste with fused borax the flux will cake rapidly. Alcohol or some other medium should be used for making the paste if it is desirable to use borax in this form. Many of the prepared fluxes have considerable percentages of boric acid which tends to make a somewhat more viscous flux and boric acid is not as active as borax for dissolving oxides. Further information in regard to fluxes can be found in papers which have been published previously, a list of which is appended to this paper.

Heating.

Figure 5 gives a brazing process chart adopted by the American Welding Society.

Improvements are constantly being made in the different methods given in the chart and the one selected depends upon such

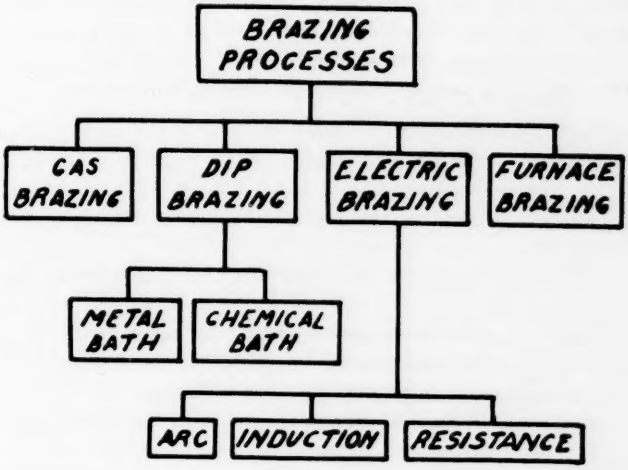


FIGURE 5.

factors as quantity of work, size of individual units, whether the work is to be done in the shop or field. All of the methods given are accepted by the Committee on Nomenclature of the American Welding Society.

GAS BRAZING: "is a brazing process wherein the brazing heat is obtained from a gas flame."

This definition covers all combinations of fuels, such as oxy-acetylene, oxy-hydrogen, oxy-city gas or natural gas and gases such as butane or propane; air acetylene and air gas.

Because of its availability and clean and efficient heat, the oxy-acetylene process is by far the most widely used method of heating for field and shop work. Recent developments of multiflame tips have increased its efficiency by speeding up production and reducing the number of rejects caused from poor heating. For brazing heavy flanges or other types of massive sections a torch illustrated by Figure 6 has been very satisfactory. Another multiple flame torch for small tubular parts is shown in Figure 7.

Efficient types of torches have been developed for the use of the other combinations of gases. Both single and multiflame units are available which may be operated by hand or held in fixtures.

Where a large number of units are being brazed by this method specially designed multiflame torches will be of great assistance in providing better and quicker heating. Important points to remember when heating by the Gas Brazing Method are:

(a) use a neutral to reducing flame—avoid oxidizing flames.
(b) the work must be heated above the flow point of the brazing alloy.
(c) let the heat of the parts to be joined flow the brazing alloy.
(d) avoid the direct impingement of the flame on the brazing alloy.
(e) both parts to be joined should be heated uniformly.
(f) large surfaces should be heated well away from the joint—this is particularly true of copper.
(g) when heating dissimilar metals, favor the metal that is the more rapid conductor of heat.
(h) when joining different thicknesses of metal, favor the heavier section.
(i) a good point to remember when heating is that the action of the flux, when heated, is a good temperature indicator and with a little practice the heat in the work can be easily determined by observing it.

DIP BRAZING: "is a group of brazing processes wherein the heat is obtained from a bath of molten metal or chemical and the filler may or may not be obtained from the bath."

METAL BATH: is a dip brazing process wherein the filler metal is obtained from the molten metal bath. For a number of reasons, metallic dip brazing is confined to joining comparatively small work such as light gauge wire. The crucible may be heated either by gas or electricity.

CHEMICAL BATH: This method of heating requires that the assembled parts be carefully supported by suitable jigs. It has the advantage of heating the members quickly and at the same time providing protection from the oxidizing effect of the atmosphere. Temperature is easily controlled in this type of furnace, which is a decided advantage. The size of the chemical

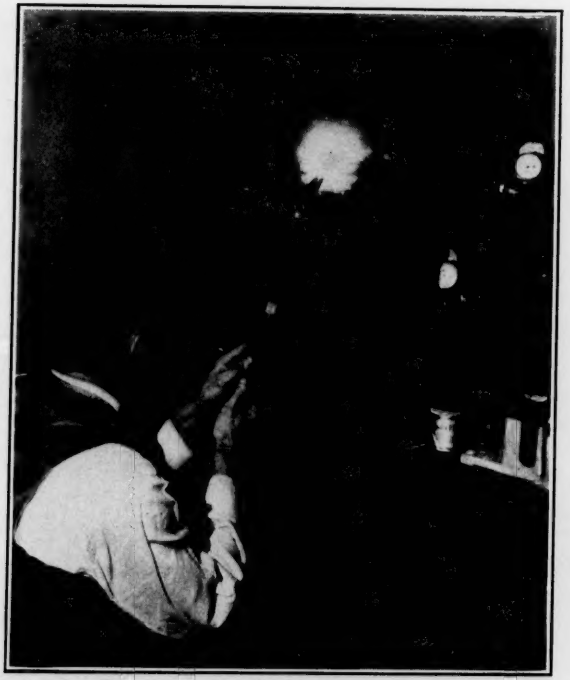


FIGURE 6.—AIR REDUCTION TWO-FLAME NO. 10 TIP HEATING A LARGE FLANGE ASSEMBLY.

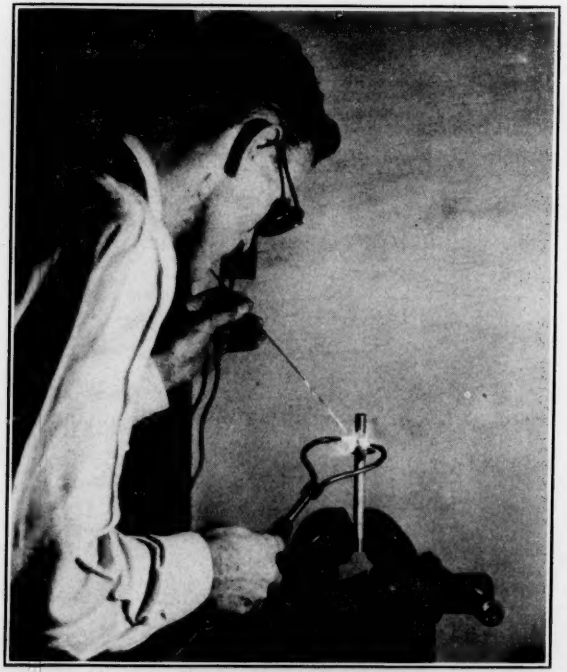


FIGURE 7.—MULTIPLE FLAME TORCH FOR SMALL TUBULAR PARTS.

bath will depend upon the size and weights of the assemblies that are to be brazed, but in general these baths should be large enough so that there is no appreciable drop in the temperature of the bath when the assembled units are immersed.

ELECTRICAL BRAZING: "is a group of brazing processes wherein the heat is obtained from an electric current."

(a) "arc brazing"—an electric brazing process wherein the heat is obtained from an electric arc formed between the base metal and an electrode or between two electrodes.

This method is not extensively used for silver alloy brazing but has been applied to joining light gauge copper with alloy No. III as a filler metal. It has also been used with Alloy No. III for repair of heavy non-ferrous castings or parts where damage from cracks or erosion can be overcome by a filler metal which flows at low temperature and has strength and resistance to wear.

(b) "induction brazing" is comparatively new. Some experiments with this form of heating were made by Lieutenant E. H. Ryan, U.S.N., while at the Bureau of Engineering and published in the JOURNAL, May 1936 [5]. Induction heating may be obtained by the following methods:

(a) high frequency arc
(b) radio tube
(c) rotary converters
(d) spark gap

The type of equipment selected for induction heating will vary according to the volume and type of work contemplated. The joints should be designed with the alloy preplaced. This heating is uniform and the temperature can be readily controlled. It would appear that this type of heating deserves consideration for those places where it is desirable to keep the heating localized. The developments in the use of induction heating in recent years for both melting and heat treating have been very rapid and the companies specializing in this field are prepared to consider all types of heating problems. It is suggested therefore if a heating problem arises which requires quick localized heating difficult to

accomplish by ordinary methods it would be desirable to consult manufacturers of induction heating equipment.

FURNACE BRAZING: Many standard types of furnaces heated by either oil, gas or electricity are available which can be used for heating assembled parts that are to be brazed with silver alloys. There are three essential points in connection with this type of brazing:

1. The entire assembly has to be brought up above the flow point of the brazing alloy.
2. A non-oxidizing atmosphere is preferred.
3. The heating should be done as rapidly as possible.

One way to provide rapid heating is to have the furnace temperature considerably above the flow point of the brazing alloy and to regulate the time during which the assembly is in the furnace so that the parts are not actually heated above the temperature required to flow the solder. If the furnace is of the conveyor type this time can be regulated by the speed of the chain. In some types of assemblies it is not possible to run this comparatively high furnace temperature because some parts would become overheated before the entire assembly had been brought to the required temperature. An interesting example of what can be done by furnace heating is a small boiler, Figure 8, which was brazed with Grade IV in an electrically heated furnace using a controlled atmosphere. A more complete description of this work has been published by Weir and Webber [7]. The boiler was of the water tube type containing 1238 copper tubes, 35½ inches long, ¾ inch od × .049 inch wall thickness and joined to two mild steel headers ¾ inch thick and 48 inches in diameter. This boiler is operated at 225 pounds per square inch pressure, the temperature of the steam being 396 degrees F. and service has been satisfactory.

RESISTANCE BRAZING: "is an electric brazing process wherein the heat is obtained by passing an electric current through the contact resistance between the areas to be brazed."

There are two general types of resistance brazing: one in which the heat is generated in the electrodes and transferred to the joint members by conduction; and the other in which the heat is

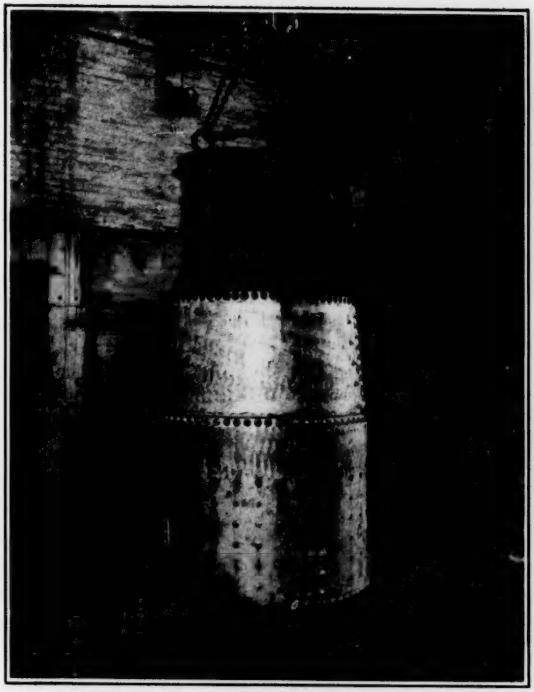


FIGURE 8.—BOILER BRAZED IN ELECTRIC FURNACE.

generated in the members. These methods were both discussed by Lieutenant Ryan as applied to tubular shapes in a paper previously [5] cited.

The term incandescent carbon brazing is sometimes used to describe the first method because the heat is generated in carbon electrodes. Portable equipment is available in which the carbons are held in tongs. Other types of electrodes can be used and as a rule the silver brazing alloy is preplaced in the joint. When applied to flats the method has the added advantage of heating under pressure. A paper [8] on incandescent carbon brazing by Reed and Edelson was presented at a meeting of Northern New York section of American Welding Society and published in the March 1938 issue of the Welding Journal.

With the second method of resistance brazing it has been possible to make lap joints approximately 3/8 inch wide on sheet copper using thin inserts of silver brazing alloy without materially affecting the strength of the copper.

Both incandescent carbon brazing and other electrical resistance types have the following advantages: Rapid heating under pressure and easy control of the heat. The heating can be confined to a small area and the pressure holds the members together thus eliminating the necessity for jigs. The cost is comparatively low and when the portable type of equipment can be used it is quite satisfactory for either shop or field work.

Corrosion.

An article on silver brazing alloys would not be complete without some reference to their corrosion resistance. The grades given in Navy specification 47S13-C are all highly resistant to the majority of corrosive conditions for which copper, copper alloys and nickel silver are used.

The problem of galvanic corrosion is most important. Silver alloys, particularly those with high silver content, are cathodic to many metals and alloys in common use under highly corrosive conditions. As galvanic corrosion is generally in proportion to the areas exposed to attack it is evident that a cathodic joining alloy would be desirable. Monel metal and stainless steels are examples of metals to which silver brazing alloys with high silver

content are cathodic under many corrosive conditions for which these metals are used. One exception, however, is in the case of joints made on stainless steel and subjected to strong nitric acid which is an excellent solvent for silver alloys and would rapidly attack the joint.

Electrical Conductivity.

The electrical conductivity of silver brazing alloys varies according to their composition. The percentage of zinc has considerable effect on lowering the conductivity of these alloys. The silver-copper eutectic which contains 72 per cent silver and 28 per cent copper actually has about 70 per cent of the conductivity of copper. The paper on Incandescent Electric Carbon Silver Brazing [8] by Reed and Edelson gives some interesting data on the resistance of joints made with silver brazing alloys. It notes that in the case of lap joints having a lap one and one-half times that of the cross section area the resistance was less than that of the copper bar used, and in the case of butt joints the resistance was only slightly greater than that of the copper. The highest percentage of silver in the alloys used in tests described in this paper was 50 per cent, and use of a still higher grade of silver alloy would improve the conductivity. In general, the higher electrical conductivity of these alloys as compared with base metal alloys makes them particularly adaptable for brazing parts of electrical apparatus where conductivity is a most important factor.

Silver Brazing Alloys at Elevated Temperatures.

Extensive tests which have been made in different laboratories indicate that the strength of these alloys falls off rapidly at temperatures above 700 degrees F. Figure 9 shows the results of one series of tests. R. C. Allen [6] advises that silver solders should not be used at a temperature exceeding 875 degrees F. Tests of silver brazed joints on high pressure steam lines show similar lowering of strength and it would appear that for severe service conditions they do not allow a sufficient factor of safety for temperatures above 450 degrees F. However, the actual conditions under which it is used may allow a design of joint which will

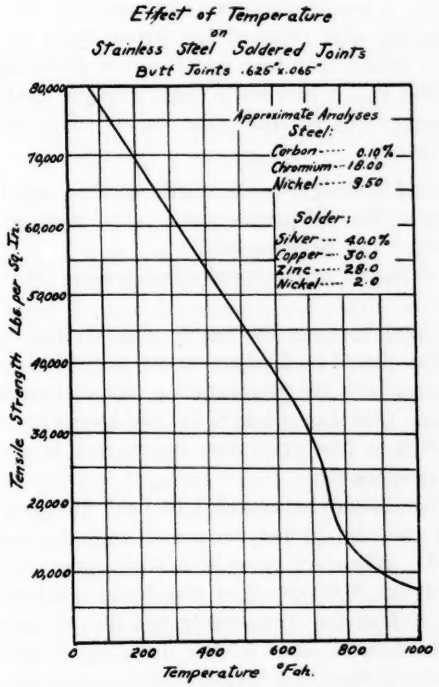


FIGURE 9.

be sufficiently strong at these elevated temperatures and all of the factors must be considered.

CONCLUSION.

Silver brazing alloys have a very important field of application in modern industrial construction. Although their first cost is higher than base metal brazing alloys per unit of weight, it has been shown that the greatest strength is obtained when joints are designed that require a very small amount of the silver brazing alloy. The other factors such as labor and fuel, combined with the lesser amount of alloy required, will in many cases make the overall cost lower than when base metal brazing alloys are used.

In some cases it has actually been demonstrated that the amount of silver brazing alloy required for certain types of joints is so much less in weight than base metal solders previously used that the actual alloy cost is less and a much stronger joint is obtained.

A few suggestions regarding the use of silver brazing alloys are as follows:

Joints should be designed with small clearances and lap or shear joints are preferable. If proper care is taken in fitting, butt joints of high strength can be obtained.

The use of inserts or preplaced silver brazing alloys is recommended.

Have all joint surfaces thoroughly clean before applying the flux. The flux should be fluid and active at the flow point of the solder. Protect both the brazing alloy and the surfaces of the joint with flux. The flux should be applied evenly leaving no bare spots. Brushing a flux paste over the surface is a satisfactory manner of using the flux.

Suitable jigs should be provided to hold the parts firmly in position and maintain proper clearances until the brazing alloy has solidified. Whenever possible a slight pressure should be applied as this has been shown to give better bonding.

Take care to heat the joint evenly and do not use any more heat than is actually required to flow the alloy, if full advantage is to be taken of these low temperature brazing alloys.

For torch brazing and bench work avoid strong drafts and varying light conditions whenever possible.

Heat the joint as rapidly as possible and do not hold the joint at the brazing temperature for a considerable period of time after the alloy has flowed.

The authors express their appreciation for the assistance given by their associates and to Handy & Harman for permission to publish this data. Also to the Walworth Company and the New York Central Railroad for photographs.

Appended List of Papers.

1. Silver Solders, by Robert H. Leach ASTM—Volume 30, April 2, 1930.

2. "Copper-Nickel (70:30) Alloy," by Mason S. Noyes, Printed in Journal of the American Society of Naval Engineers, Vol. XLVIII, No. 1, Feb., 1936.

3. "The Navy's Soldered Fittings," by Mason S. Noyes, Printed in Journal of the American Society of Naval Engineers, Vol. XLVII, No. 1, February, 1935.

4. Instructions for making silver soldered joints and composition soldered fittings—Bureau of Engineering B-172—B-178. Also composition soldered union tube fittings Bureau of Engineering, 3S-525, 3S-526, 3S-527 and B-117.

5. "Silver Soldering by Electricity," by Lieutenant P. H. Ryan, U. S. N.—Reprinted from Journal of the American Society of Naval Engineers, Vol. XLVIII, No. 2, May, 1936.

6. "Steam Turbine Materials for High Temperatures," Symposium on Effect of Temperature on the Properties of Metals—Joint meeting American Society for Mechanical Engineers—ASTM—June 23, 1931.

7. Brazing Tubes in High Pressure Boilers with Silver Alloys, by A. W. Weir and H. M. Webber—American Welding Society Meeting, October 18, 1938.

8. "Incandescent Electric Carbon Silver Brazing," by Walter Reed and Leo Edelson. American Welding Society—Feb. 17, 1938, meeting, Northern New York Section.

"Brazing with Silver Solders," by Robert H. Leach, American Welding Society, Oct. 1-5, 1934.

"Metals Are Brazed in Controlled-Atmosphere Electric Furnaces," by H. M. Webber—Reprinted from Steel, Aug. 12 and 26, 1935.

"When and How Silver Solders Are Used," by Robert H. Leach—Proceedings of American Welding Society for Testing Materials, Vol. 30, April 2, 1930—Metals and Alloys, Nov., 1931; American Welding Society Journal, October, 1934.

MOVING PICTURE MEASUREMENTS OF A VESSEL'S SPEED THROUGH THE WATER.

By Commander P. B. Eaton, (E), U. S. Coast Guard, Member.*

One essential in testing vessels for maneuvering and speed changing characteristics is to determine the speed through the water at any time during the maneuver. A method of determining speeds at short intervals by using a moving picture camera is described.

The camera is mounted so that the line of sight is at right angles to the keel line. It is pointed down in order to photograph the water at a few feet from the vessel's side. When the vessel is underway, and the camera is operated a series of pictures of the water will be obtained. The surface of the water has foam or bubbles and upon examination of the film, any particular formation will be readily traced from the leading edge of the film to the trailing edge, so that the number of frames exposed during the passage of the formation across the field of the camera may be counted. Knowing the number of frames exposed per second and the width of the field, the motion of the camera and hence the speed of the vessel can be calculated.

Let F equal number of frames in which a configuration passes from one edge of the film to the other.

H equals horizontal dimension of field of camera in feet.

C equals speed of camera frames per second.

K equals speed of vessel knots.

Then K equals $\frac{C \times H \times 3600}{F \times 6080}$

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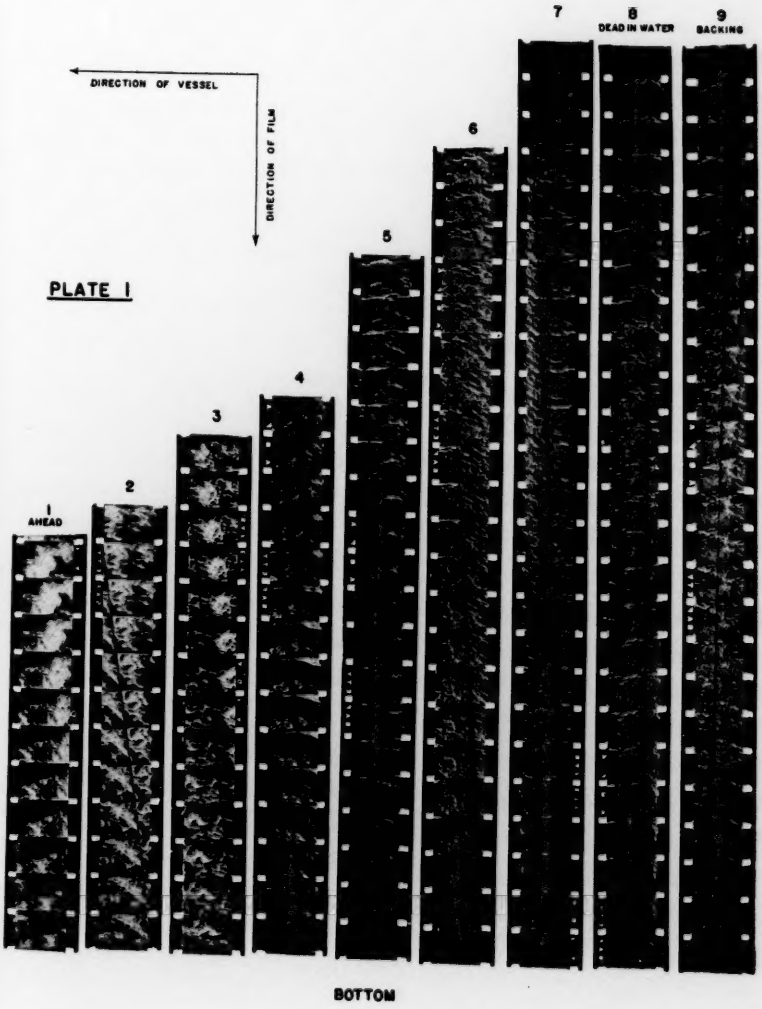
DIRECTION OF VESSEL
DIRECTION OF FILM
1
AHEAD
2
3
4
5
6
7
8
DEAD IN WATER
9
BACKING
BOTTOM

PLATE I

For any runs with camera mounted in same position and operated with same speed, C and H are constant and K equals $\frac{\text{a constant.}}{F}$

For example, a camera is used whose speed (C) is found to be 370 frames in a 20 second run of 18.5 frames per second. It is exposed over the vessel's side as described above and examination of the film in the first 18.5 frames shows a configuration passing from one edge of the film to the other in 8 frames (F). The field of exposure on the film has been determined to be 5.75 feet (H).

One knot equals rate of $\frac{6080}{3600}$ feet per second.

Then vessel's speed in Knots equals $\frac{18.5 \times 5.75 \times 3600}{8 \times 6080}$ equals 7.87.

The horizontal dimension of the field of the camera can be determined as follows. The camera is first set up at a known distance from a surface on which are mounted horizontal scales divided in feet and inches and a few frames taken and developed.

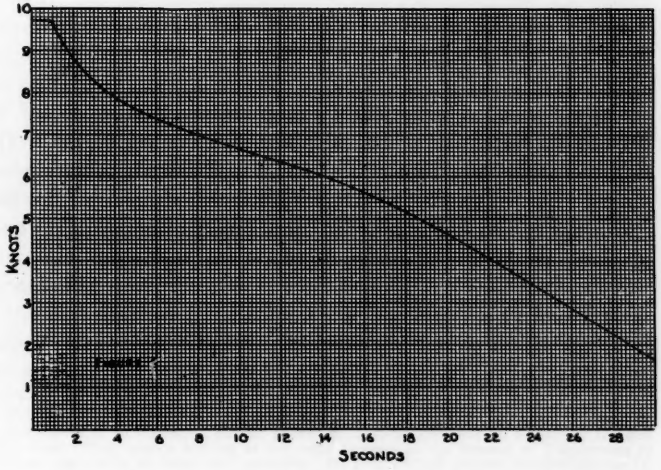

FIGURE 1.

When the camera is set up on the vessel, the distance from the camera to the water is measured and the horizontal dimension of the field is easily found as the ratio of width of fields equals the ratio of distance of camera to field.

Plate I shows various strips of film taken in the manner above described on a tug boat. Lines have been added to the film showing how the configurations travel from side to side of the film for decreasing speed ahead (1) to (8). (8) dead in the water (9) starting astern. Figure 1 shows a plot of the speed against time for backing from standard speed ahead on the tugboat.

In running a series of backing tests, it is recommended that a title board be prepared indicating the serial number of the run, speed the vessel is making when the run starts, time, and any other essential data. At the preparatory signal for the run the title board is held in front of the camera and photographed. At the signal to back the camera is started and run continuously, care being taken to keep the motor spring of the camera wound during the run.

THE NAVAL INSPECTION SERVICE.

By Captain R. C. Davis, U. S. Navy (Retired), Member.*

Veri inquisito atque investigatio.

Inspection of material is the search for truth *as to actual condition. Since the early days of ship construction the need for inspection has increased to meet the rapid advances in scientific developments, to control the attending complexities in the uses and applications of materials. The Inspector plays an important part in aiding the manufacturer and the designer as well as in protecting the interests of the consumer. The Navy, through him, desires most earnestly to encourage industry in general and manufacturers in particular in the production of suitable naval materials.*

The Naval Inspection Service is a highly important Naval activity, but one whose organization and operations are not widely experienced and therefore not fully appreciated by the Navy at large as an essential safeguard. This is because only a very small percentage of the total number of officers are assigned to the duties of Inspector of Naval Material. While many connected with the Navy have a general impression regarding the nature of and the necessity for the inspection and testing of Naval materials; it is difficult for one who has not had actual experience in a field inspection organization to visualize its operations and realize the necessity for inspection at place of manufacture rather than at destination.

As here employed, the subject title includes the various organizations concerned with the inspection and testing of all classes of Naval materials, such as electrical systems, naval aircraft, ordnance,

* Captain Davis served for a number of years as an Inspector of Naval Material in active charge of an inspection district as well as a Naval Inspector of Machinery for new ship construction, besides serving as Inspector General in the Bureau of Engineering in general supervision of those field activities. He prepared the present instructions for Inspectors of Naval Material and the Inspection Manual for Naval Inspectors of Machinery.

radio and navigation equipment, used for the construction or repair of ships' hulls and machinery, and the power plants, buildings and dock equipment of Navy Yards and other shore activities of the Naval establishment.

This service includes Inspectors of Naval Materials at Manufacturing Plants, Naval Inspectors of Machinery and Superintending Constructors at the private shipbuilding yards, Naval Inspectors of Ordnance Materials at both manufacturing plants and shipyards, and Inspectors of Naval Aircraft at Aircraft Manufacturing plants. In general, inspection of shipbuilding at shipyards and of naval aircraft at aircraft manufacturing plants is primarily shop inspection and final assembly inspection and test in the ship; whereas field inspection of the unfinished, semi-finished and finished materials refers to the materials inspected at manufacturing plants by Inspectors of Naval Material for use by Shipbuilders and Aircraft builders as well as for the general use of the Fleet, the Navy Yards and other activities of the shore establishment of the Navy. This article applies primarily to field inspection at manufacturing plants by Inspectors of Naval Material. It may be applied equally well to any other inspection activity.

The Naval Inspection Service had its inception in the first Naval shipbuilding program, when the construction of six frigates was authorized by the Congress of 1794. This group included the historic *Constitution* * which was constructed under contract number one. Ship captains and other officers were appointed, and they inspected ship construction, ship building materials, naval ordnance, accessories, equipment and naval stores. Since that modest beginning, this service has continued to function, and has progressed with the changes from wooden hulls to steel hulls and from sails to modern steam turbines, oil engines and high powered electric motors for ship propulsion. It has made notable contributions to practically all branches of private industry and to advancement in the naval sciences in general. It is probably one of the oldest and most extensively organized inspection services of the various government departments. The Navy originated and developed most of the early important hull and machinery designs and specified the

* A ledger giving the account of the construction of the *Constitution*, written in excellent penmanship style by the Chief Clerk of the then Naval Committee, is on file in the Navy Department library.

present modern ones which were developed by the various ship yard contractors in collaboration with the Navy Department. Today, the Naval Inspection Service and its several component parts are well organized and administered efficiently and economically by experienced commissioned officers under the supervision of the technical bureaus of the Navy Department.

For that which is commonly known as "field inspection" at the manufacturing sources, the Department has divided the United States geographically into twelve Naval Inspection Districts, with inspection headquarters located in the industrial centers where the inspection loads are greatest. For purposes of economy and to render prompt inspection service, branch inspection offices, with Resident Inspectors in charge and operating under the main office, are established in other industrial centers within the same district. Each district is under the command of and administered by a senior Naval officer designated as Inspector of Naval Material. The personnel concerned with the inspection of naval materials may be divided broadly into three principal groups, namely:

1—Commissioned Officers who have acquired technical knowledge through education and through experience in the operation and maintenance of material and machinery on ship board, construction of new ships, or repair of ships in the Fleet or at the Navy Yards.

2—Civilian assistant inspectors, qualified for their appointments by reason of their technical education or manufacturing experience and familiarity with the inspection and testing of materials, mill practices, shop processes, production methods and with important shipbuilding materials and machinery.

3—The laboratory personnel of the various Naval and other government activities who make the chemical analyses, metallurgical or other examinations, or conduct special tests of materials as to their compliance with the specifications and suitability for Naval use.

Normally, the Assistant Inspectors conduct or witness the specified basic physical tests of materials under their inspection at the contractor's laboratories.

Since the civilian Assistant Inspectors are such an important factor in the daily routine of inspection and since no organization, no matter how carefully planned, standardized as to methods and efficiently managed, is any better than its operating personnel, a brief sketch of those Inspectors is in order.

In the first place, the Navy Department prescribes strict technical qualifications for its inspectors. Only men of ability, experience, and good character are selected for appointment after they have been classified and graded by the Civil Service Commission. Specialists are selected in each inspection organization to inspect and test special materials, machinery or equipment assemblies which require special knowledge and experience. Many are general inspectors, capable of inspecting and testing many classes of Naval Materials after becoming familiar with Naval Contracts, methods of inspections and tests and Navy Department Specifications.

A considerable period of instruction and much experience are required before the average inspector from civil life becomes proficient in his duties as an Inspector of Naval Materials. He has to discard many of his ideas regarding commercially suitable materials for those that are acceptable for Naval purposes. That is one of several reasons why no other government agency or consolidated federal inspection service can inspect properly and efficiently for the Navy. They lack the essential and necessary Naval experience in the actual use or operation of the material. While laboratory and mill experience are valuable aids in the general inspection plan, these are of secondary importance. The Navy must keep control of the inspection of its own materials for national defense purposes as well as for other reasons.

The civilian Assistant Inspectors come principally from industry and a few from universities. Many, who have not had the benefit of laboratory work or a regular college engineering degree, acquire certificates from night courses in engineering colleges. They are respected for their ability, character, integrity and prompt and business-like methods of conducting inspections as well as for their strict, impartial and conscientious performance of duty. They take great pride in their work and are as loyal to their oath and to the Navy as any Government official. Their anchor stamp placed

upon material, inspected and accepted by them, represents their word of honor in which the Navy may place the highest confidence. Their inspection efficiency is very high and errors in judgment are indeed rare. Practically all major material and workmanship defects are discovered during field inspection or during the shop or laboratory tests. Many of these would not be noticed at destination.

The valuable experience of the officers as to the operation and uses of the materials under various service conditions, together with the mill experience of the civilian Assistant Inspectors and the availability of excellent Government laboratory facilities, is a combination deemed capable of rendering highly efficient service and giving the Navy maximum protection as to the integrity of its materials. In addition to the foregoing, the Inspection Service is fortified by the advice and support of the various Bureaus of the Navy Department whose officers, material engineers and technical personnel follow the design, application and operation of materials and machinery in the Fleet and their inspection and tests in the field. Also, a most important aid is the Fleet itself, which is a laboratory on a grand scale, submitting reports periodically on the behavior of materials and machinery under the various service conditions of operation. This enables the technical bureaus to improve design, select materials better suited for service, change material specifications and methods of inspection or test and keep the inspection service informed. To meet the rigid demands of service, the bureaus are continually engaged in experimental testing and research work at Naval laboratories specially equipped for the purpose, with resulting improvements in the character, design or application of the materials and in manufacturing methods. A rather notable recent instance of this class of work is described in the article on steel casting design by Mr. C. W. Briggs of the Naval Research Laboratory as published in volume 50, May 1938, issue of the JOURNAL.

While the foregoing is cited as a single example, great credit is due to the Naval Engineering Experiment Station, to the Naval Materials Laboratory, and to the Naval Boiler Laboratory for their pioneer work and numerous contributions to the development and improvement of Naval materials, machinery and equipment

designs and for the high material standards that exist in the Navy today. Similarly, the Navy Yards have contributed their fair share of this development or new applications of materials to meet special Naval needs. Also, it is desired to give credit here to the many prominent manufacturers who have made valuable contributions aiding the Navy on experimental and research work in the development of new materials, new manufacturing processes and new designs having Naval applications.

Inspection at Place of Manufacture.

In the case of the Navy dependable material free from injurious defects is a necessity. Here we are concerned with materials for fighting ships as distinguished from materials for ordinary commercial purposes, although there are many materials in common use by both. Naval ship demands are more rigid than those encountered in commercial practice for similar materials because they have to withstand much more severe service and additional loads and stresses due to rapid changes between low and full power, to temperature operating conditions, to working of ships in heavy seas, to vibration, shock by gunfire, torpedoes and aerial bombs, to unevenly applied torsional loads, as in propeller and main machinery shafting, to difficulties of lubrication on account of the pitching and rolling of the ship, and to corrosion and corrosion fatigue of metals exposed to salt water or to salt laden atmosphere.

Casualties or break-downs due to material defects may not be serious in shore installations where, by merely utilizing the telephone, replacements may be expected on short order. On a ship at sea, such prompt service cannot be rendered and certain types of material defects may lead to serious casualties, endangering not only the lives of the operating personnel but also the ship itself. In the event of war, material defects, unless detected by proper inspection at the manufacturing source, may lead to casualties involving not only the loss of the ship but also the loss of a crucial sea engagement. Also, in such cases time for making replacements is a most precious and priceless thing.

In addition to the foregoing military reasons, the method of making Government purchases and awarding contracts to the lowest responsible bidder renders it imperative to conduct the in-

spection at source of manufacture and to make the necessary tests of practically all contract Naval materials of which there are many thousand varieties. Today, most large industrial establishments have found it necessary for reasons of efficiency and for protection of their financial interests, to maintain an inspection department of their own. They have found this necessary, not only for the detection and correction of material and workmanship defects of their own production in order to insure a good name or reputation, but also for materials and equipment purchased from other manufacturers. The various railroad companies found it necessary from the very beginning of railroad operation to perform most of their inspection and tests of material and machinery assemblies at place of manufacture. In the case of the railroads, inspection at source is mandatory not only to avoid loss of life but also to avoid heavy damage awards resulting from law suits. In contrast to former days, when the presence of a Naval Inspector in a shop for inspection purposes was looked upon with apprehension to be suffered only, he is welcomed today by most manufacturers who have faith in their products and the knowledge that the inspector is there to cooperate with them in producing materials satisfactory for the Naval Service.

During the course of a year, the Navy Department makes purchases from several thousand manufacturers. Contracts are also awarded to material brokerage concerns which, having no manufacturing facilities of their own, shop around to purchase the cheapest grades of material that will be accepted under the specifications. In one large Naval District alone, the Naval Inspector will inspect at different times the products of a thousand plants. Many Naval contractors purchase from other manufacturers (sub-contractors) and that material must be inspected also before shipment and use by the contractor. The possibilities of using improper materials for a particular application as well as defects in both materials and workmanship are ever present. In preparing purchase orders on sub-contractors, a contractor's purchasing department may omit the essential Naval specification, fail to specify Navy inspection, or depart from the material specifications, dimensions or finish as prescribed by the latest approved plan. In certain classes of finished products there are an appreciable number of recurring defects in

material or workmanship which are detected and corrected by the field inspectors, who, due to their knowledge of the manufacturer's equipment and skill of his personnel, know for what and where to inspect. In the event of inspection at destination, many such defects would most likely remain unobserved until it was too late. Even with highly skilled machinics, and in many cases where there is an active progress of production, or bonus systems, or other means employed to increase production, or where they are behind on promised delivery dates, at least one out of a group of several men may produce faulty work. In some cases, a man's tenure of employment depends upon his accuracy as well as his speed of production and it is only human for him to endeavor to hide all faulty work even from his own supervisors. In cases of machinery assemblies, the detection and correction of defects and errors after the assembly, or after shipment, is most difficult, if not impossible, becoming evident only through failure in service.

There are many manufacturers who give full cooperation to the Government, whose products require no inspection as to quality and who are entirely dependable. The products of these need no inspection, but the Government is doing business with several thousand manufacturers, many of whom are furnishing materials or services for the first time and some few have used questionable materials and methods. To be fair to all, no one can be excused from inspection of his products. The chances of error would be too great and entirely unwarranted for national defense purposes. It would be not only unwise but also an unsafe policy. The Navy is the best judge as it has the actual operating experience and is more fully cognizant of its own needs than the manufacturer.

From its own experience, the Navy Department has found it necessary to require the inspection of every piece or item of material and machinery employed by a contractor in new ship construction. A shipyard is primarily an assembly yard, the shipbuilding company making most of its purchases of building materials, machinery and equipment from a considerable number of outside suppliers from plans on which the materials are specified and approved by the Navy Department. Therefore, it is important, not only as a protection to the Navy but also to the shipbuilding contractor, to conduct the necessary inspections and tests prior to

shipment from the manufacturer's works. This involves a very considerable quantity and value of material used for new ship construction in addition to the large volume of materials under constant inspection for use by the Fleet, the Navy Yards and other shore activities of the Naval establishment. Too, the Naval Inspection Service is requested by other departments of the Government to conduct the field inspection of materials and machinery ordered for various Government projects.

It has been suggested from time to time that inspection in the field delays unnecessarily the deliveries of the material at destination. In a few isolated cases that may be true, but in the long run field inspection is a time saver. Many manufacturers prefer inspection at the source because, although they have absolute faith in their own products and ability, such inspection is added insurance against the delivery of defective material with resultant delay in making replacements. Some prefer it as a protection to them against the heavy expense of replacements and transportation costs in the event of inspection and rejection at destination. Some feel that Navy inspection in their shops assists in maintaining their standards of quality by keeping their employees on the alert to put forth their best efforts when they know that the final product is to be inspected by men who are familiar with the material and their work. The president of a large manufacturing concern informed the writer regarding this feature. Some consider inspection in the field a protection against certain types of competitors who use cheaper grades of materials and workmanship. In many cases, the fact that a manufacturer's material has passed Navy inspection gives that manufacturer a good standing in the competitive field and, not infrequently, the fact that he meets Navy specifications aids him in selling commercially.

Normally, field inspection is conducted within two days after receipt of the manufacturer's notice by the Naval Inspector that the material is ready. In some cases the inspection is made on the date of receipt of the notice but this is not common, since, for reasons of economy, it is necessary for the Inspector to schedule the detail of his assistants two or three days in advance for inspections under current orders at the various manufacturing plants. However, during their travels from plant to plant, or town to

town, the Assistant Inspectors keep in communication with their main headquarters and they may be diverted to other inspections to meet emergencies.

The more common causes within a manufacturer's control for delays in delivery of contract materials or services are (1) those due to late planning, or starting, or progressing the work in the shops by the manufacturer, (2) lack of complete knowledge as to plan and specification requirements which should have been furnished the production department by the sales or contract departments of the manufacturer, (3) late preparation and approval of drawings where required, (4) failure to prepare promptly the sub-orders for purchase and inspection of needed materials from other suppliers, (5) failure to eliminate by proper shop inspection obviously unsuitable or defective materials and workmanship, (6) failure to lay out the material for inspection as a time saver when there are several hundred pieces of the same item, (7) failure to make adequate preparation for conduct of tests, (8) delay in starting replacements for rejected items, (9) delays in preparing for and making shipments, (10) failure of the manufacturer to give the required two days' notice that the material will be ready, (11) general lack of familiarity especially by a new manufacturer, with the Naval requirements, methods of doing business and preparation of needed reports and other correspondence. The inspectors in the field are required to assist a new manufacturer with regard to the Naval requirements and specifications.

Delays in the deliveries of materials make it difficult for the management to meet the shop schedules and delivery dates, to maintain a more constant work load and to avoid suspension of men from work. However, no time will be saved if the material is found defective at destination and it becomes necessary to replace it, or to work on it to make it usable thereby adding to the costs. In fact, in practically all cases, inspection at source expedites deliveries. For example, consider the question of steel castings with their inherent defects requiring the most searching examination and analyses. There would be much loss of time involved if the contractor was permitted to ship, without inspection, castings containing defects which he considered would be acceptable commercially but would not be acceptable for Naval purposes either by the in-

spector in the field or at destination. All known defects are most carefully explored by the field inspector. Where welding is authorized in castings subject to high stresses or pressures the soundness of the work is usually further verified by radiographic examination or by other means. In such cases both time and costs are saved to the Naval Activity using the material. The technical bureaus have issued instructions to the Naval Inspection Service on the inspection and testing of steel castings and the average field inspector is thoroughly cognizant of the Navy requirements as to the acceptability of this class of materials.

With the foregoing in mind, let us visit the headquarters of an Inspection District and accompany the Assistant Inspectors during their inspections of an important order. We will omit the various but important details of office procedure except to mention the fact that each District Headquarters presents a scene of great activity in the daily handling of a voluminous correspondence and the holding of conferences between the Inspector and his Assistants, or with manufacturer's representatives on matters concerned with current and incoming contracts and manufacturer's purchase orders on sub-contractors.

For purpose of illustration, we will select a private shipyard purchase order on a turbine manufacturer for a set of main propelling machinery units for a ship. This class of machinery is selected as it involves also some important materials furnished by outside suppliers where these must be inspected by other inspectors prior to use for fabrication and construction purposes by the turbine manufacturer. Only men who are qualified and are familiar with the construction and operation of Naval turbines are selected to conduct the inspection and test during manufacture and assembly.

The order includes blue prints of shipyard plans which have been approved by the Bureau of Engineering and these together with the order are checked carefully by the Naval Inspector at the shipyard before release for inspection purposes. The order is given a general check also by the Inspector of Naval Material for completion of details requisite for inspection. Next, follows the manufacturers' purchase orders on other manufacturers, involving one or more inspection districts, for such important parts as steel

castings for the turbine cylinder casings, rotor forgings, turbine blade materials, valves, bolts, nuts, piping and insulating materials. These purchase orders are checked carefully for errors, omissions and the standard data required on all orders for the conduct of inspection.

The shipyard order with the accompanying blue prints are turned over next to the Assistant Inspector assigned to conduct the inspection of the turbines during their manufacture, assembly and test. A commissioned officer is assigned in general charge and witnesses all important tests. In view of the extent of work involved, an inspection procedure is arranged with the manufacturer and a schedule of tests prepared which must conform with the contract plans and specifications including the Special Ship Specifications and the General Specifications for Machinery. After careful checking, the turbine manufacturer's purchase orders on outside suppliers are assigned to other Assistant Inspectors who are familiar with the material involved. If ordered from a sub-contractor in another district, the orders after checking are forwarded to the Naval Inspector in charge of inspection in that district for his action.

Probably the two classes of turbine materials that present the most difficulty from manufacturing and inspection viewpoints are the steel castings for the turbine casings and to a less extent the steel forgings for the rotors. While foundry technique has improved considerably within the past generation, much difficulty is still encountered in producing sound castings. Here is where field inspection is of increased importance.

The foundry having notified the Inspector when the castings are ready for inspection in the green or as cast condition, after they have been thoroughly cleaned, he proceeds forthwith and conducts a careful surface inspection for the usual defects. He makes a check from the plan of the dimensions of the cylinder body, wall thicknesses, flanges, pads, bosses, all openings, distortion of casting, displacements et cetera. Casting defects are explored, the defective metal being removed in his presence. If shrinkage cracks are suspected, he may order the cavity to be acid etched and all unsound metal removed for further examination. If the examination discloses that the defects are not serious, depending on their

extent and location, and are capable of satisfactory repair by welding, he so reports to his superior and awaits his authority. If authorized, he witnesses the welding which must be performed by qualified welders in accordance with Naval requirements. After welding, the casting is given the regular anneal or heat treatment. Most turbine manufacturers prefer to do their own welding as they are better equipped and have more scientific control of the process. In such cases, they require all surface defects to be explored as to their acceptability to the Navy before shipment. After the anneal or heat treatment of the casting, test coupons are removed, machined and tested for compliance with the specified physical properties. At the same time drillings are taken for chemical analysis. This analysis is of particular importance in the case of alloy steels where welding may be involved. Each casting is stamped by the inspector with a standard Naval inspection stamp indicating the status of its acceptability to the Navy. This identification is also a guaranty to the Naval Inspector at the turbine manufacturer's works that the material has met the specification requirements chemically and physically in so far as the surface inspection indicates. In addition a special inspection and shipment report is made. If any welding is authorized, a radiographic examination of the weld is made. The welds are performed by the turbine manufacturer after rough machining and then the casting given a stress relief anneal for relieving welding stresses. Standard instructions to the Inspection Service covering this phase of inspection have been issued by the Bureau of Engineering.

The inspection of the rotor forgings at the mill includes the usual surface inspection and dimensional checking from the forging plan. Discards are taken from the top and the bottom of the ingot as prescribed by the specifications to insure freedom from undue segregation and piping. The forging operations of the heated ingot having been completed, the rotor is given a heat treatment, air cooled, rough machined and again heat treated to refine the grain. The test pieces are removed, machined and placed in the testing machine and tested for their compliance with the specified physical properties. In addition, an electro-magnetic test is conducted for the presence of shrinkage cracks, seams and cavities. This is a positive test for disclosing these defects which are not apparent

under the ordinary magnifying glass. A hole is next bored axially through the center of the forging and a careful borescope examination made for the presence of forging defects. Finally, a heat indication test of the rotor is made to determine its stability and freedom from any tendency to distort when subjected to the high temperature conditions encountered in service. Buttons and drillings are taken for the metallographic examination and chemical analysis respectively both of which are very important. If the forging complies with the specifications and meets the tests, it is anchor stamped by the inspector for identification purposes and a full report is forwarded to destination. In the cases of both castings and forgings they are further identified by serial numbers which are stamped upon them and entered on the inspection report.

The preceding descriptions of inspection procedures are given somewhat briefly to illustrate the necessity for field inspection of important Naval materials. Both the turbine manufacturer and the shipbuilder, as well as the Navy, are concerned to see that no material defects are permitted to enter into the construction of machinery so necessary and vital to the ship's operation. Searching examinations and tests are conducted similarly of the other turbine materials as prescribed by the specifications.

The manufacturer proceeds with the fabrication of parts and their assemblies as the materials are received in store where they are identified or checked by the local inspector. The shop inspection consists of the usual daily trips by the senior inspector and his assistants through the different shops to observe the various machining and assembly operations. The turbine castings are carefully checked on the layout table and, after rough machining, they are again inspected for the usual casting defects. If welding is involved, the soundness of each weld is verified by a radiographic examination. After annealing, the bases and covers are assembled and the tightness of the castings determined by a hydrostatic or air test. The turbine blade materials are gauged by the inspector before they are used for installation purposes. All finished bores, inner and outer, bearings, journals, workmanship and finish on individual items are inspected or checked. After the casings and the rotors have been bladed, the blade clearances, bearing clearances, thrust clearances, and the rotor position or clearance are

checked and recorded on the special form provided for the purpose. As the individual units are completed, they are balanced dynamically. Finally, an entire set of units for a complete shaft, including auxiliaries in use, are assembled and operated at different speeds, designed pressures and temperatures for the various load conditions. Effort is made to simulate the ship contract trial conditions as to speeds, pressures, steam temperatures, propeller loads, horsepower, ease of handling, maneuvering et cetera. Data is collected as to water rates. Turbine manufacturers, not equipped to run such tests of a complete assembly, run operating tests on a test stand of each unit from low to full and overload speeds within prescribed time limits employing prony brakes or other means to simulate the load. This, of course, is not as satisfactory as operating the tests of a complete assembly. Upon completion of all tests, inspection reports, together with such data as may be required for installation and operation purposes and the manufacturer's machinery instruction booklet, are forwarded to the Naval Inspector at the building yard.

Conclusion.

The reasons for the Inspection Service and for inspection at the plant of the manufacturer may be summarized as follows:

(1) To enable the Navy to secure the highest possible dependability in materials and workmanship employed for the construction or operation of ships for national defense purposes;

(2) To protect the operators of the materials;

(3) To protect the financial interests of the Government, a necessity in its system of awarding contracts to the lowest bidder;

(4) To detect and correct defects in material or errors in workmanship prior to shipment, many of which would be unobserved at destination;

(5) To insure the use of materials in accordance with contract specifications and to prevent the substitution of inferior or unauthorized materials;

(6) To insure that the materials are used as specified by the design requirements. This is not only important to the users of the materials but also to the Naval architects and engineers who prepare the designs in the drawing rooms but seldom see the materials and machinery under service operating conditions;

(7) To guarantee that the material will meet the calculated stresses and the designed factors of safety and the protective features, which are important for those purposes alone and, in particular, for designs which involve weight saving features and safety factors connected therewith;

(8) To aid and protect the *requiring* and *purchasing* agencies of the Government in carrying out their missions which are highly important in any plan of material procurement.

#/D	570°	580°	590°	600°	610°	620°	630°	640°	650°	660°
550	1274.90	1281.50	1287.90	1294.30	1300.55	1306.80	1312.85	1318.90	1324.85	1330.80
551	1274.79	1281.40	1287.81	1294.21	1300.47	1306.72	1312.78	1318.83	1324.79	1330.74
552	1274.68	1281.30	1287.72	1294.12	1300.38	1306.64	1312.70	1318.76	1324.72	1330.68
553	1274.57	1281.20	1287.63	1294.03	1300.30	1306.56	1312.63	1318.69	1324.66	1330.62
554	1274.46	1281.10	1287.54	1293.94	1300.21	1306.48	1312.55	1318.62	1324.59	1330.56
555	1274.35	1281.00	1287.45	1293.85	1300.13	1306.40	1312.48	1318.55	1324.53	1330.50
556	1274.24	1280.90	1287.36	1293.76	1300.04	1306.32	1312.40	1318.48	1324.46	1330.44
557	1274.13	1280.80	1287.27	1293.67	1299.96	1306.24	1312.33	1318.41	1324.40	1330.38
558	1274.02	1280.70	1287.18	1293.58	1299.87	1306.16	1312.25	1318.34	1324.33	1330.32
559	1273.91	1280.60	1287.09	1293.49	1299.79	1306.08	1312.18	1318.27	1324.27	1330.26
	.67	.65	.64	.63	.63	.61	.61	.60	.60	.59
560	1273.80	1280.50	1287.00	1293.40	1299.70	1306.00	1312.10	1318.20	1324.20	1330.20
561	1273.70	1280.40	1286.91	1293.32	1299.62	1305.92	1312.03	1318.13	1324.13	1330.13
562	1273.60	1280.30	1286.82	1293.24	1299.54	1305.84	1311.95	1318.06	1324.06	1330.06
563	1273.50	1280.20	1286.73	1293.16	1299.46	1305.76	1311.88	1317.99	1323.99	1329.99
564	1273.40	1280.10	1286.64	1293.08	1299.38	1305.68	1311.80	1317.92	1323.92	1329.92
565	1273.30	1280.00	1286.55	1293.00	1299.30	1305.60	1311.73	1317.85	1323.85	1329.85
566	1273.20	1279.90	1286.46	1292.92	1299.22	1305.52	1311.65	1317.78	1323.78	1329.78
567	1273.10	1279.80	1286.37	1292.84	1299.14	1305.44	1311.58	1317.71	1323.71	1329.71
568	1273.00	1279.70	1286.28	1292.76	1299.06	1305.36	1311.50	1317.64	1323.64	1329.64
569	1272.90	1279.60	1286.19	1292.68	1298.98	1305.28	1311.43	1317.57	1323.57	1329.57
	.67	.66	.65	.63	.63	.61	.61	.60	.60	.59
570	1272.80	1279.50	1286.10	1292.60	1298.90	1305.20	1311.35	1317.50	1323.50	1329.50
571	1272.70	1279.40	1286.01	1292.51	1298.82	1305.12	1311.27	1317.42	1323.43	1329.43
572	1272.60	1279.30	1285.92	1292.42	1298.73	1305.04	1311.19	1317.34	1323.35	1329.36
573	1272.50	1279.20	1285.83	1292.33	1298.65	1304.96	1311.11	1317.26	1323.28	1329.29
574	1272.40	1279.10	1285.74	1292.24	1298.56	1304.88	1311.03	1317.18	1323.20	1329.22
575	1272.30	1279.00	1285.65	1292.15	1298.48	1304.80	1310.95	1317.10	1323.13	1329.15
576	1272.20	1278.90	1285.56	1292.06	1298.39	1304.72	1310.87	1317.02	1323.05	1329.08
577	1272.10	1278.80	1285.47	1291.97	1298.31	1304.64	1310.79	1316.94	1322.98	1329.01
578	1272.00	1278.70	1285.38	1291.88	1298.22	1304.56	1310.71	1316.86	1322.90	1328.94
579	1271.90	1278.60	1285.29	1291.79	1298.14	1304.48	1310.63	1316.78	1322.83	1328.87
	.67	.67	.66	.63	.63	.62	.62	.60	.60	.59
580	1271.80	1278.50	1285.20	1291.70	1298.05	1304.40	1310.55	1316.70	1322.75	1328.80
581	1271.70	1278.41	1285.11	1291.61	1297.97	1304.32	1310.48	1316.63	1322.68	1328.73
582	1271.60	1278.32	1285.02	1291.52	1297.89	1304.24	1310.41	1316.56	1322.61	1328.66
583	1271.50	1278.23	1284.93	1291.45	1297.80	1304.16	1310.33	1316.49	1322.54	1328.59
584	1271.40	1278.14	1284.84	1291.34	1297.72	1304.08	1310.26	1316.42	1322.47	1328.52
585	1271.30	1278.05	1284.75	1291.25	1297.63	1304.00	1310.18	1316.35	1322.40	1328.45
586	1271.20	1277.96	1284.66	1291.16	1297.55	1303.92	1310.11	1316.28	1322.33	1328.38
587	1271.10	1277.87	1284.57	1291.07	1297.46	1303.84	1310.03	1316.21	1322.26	1328.31
588	1271.00	1277.78	1284.48	1290.98	1297.38	1303.76	1309.95	1316.14	1322.19	1328.24
589	1270.90	1277.69	1284.39	1290.89	1297.29	1303.68	1309.88	1316.07	1322.12	1328.17
	.69	.67	.65	.64	.64	.62	.62	.61	.61	.59
590	1270.80	1277.60	1284.30	1290.80	1297.20	1303.60	1309.80	1316.00	1322.05	1328.10
591	1270.69	1277.50	1284.20	1290.71	1297.11	1303.51	1309.72	1315.92	1321.98	1328.03
592	1270.58	1277.40	1284.10	1290.62	1297.02	1303.42	1309.63	1315.84	1321.90	1327.96
593	1270.47	1277.30	1284.00	1290.53	1296.93	1303.33	1309.55	1315.76	1321.83	1327.89
594	1270.36	1277.20	1283.90	1290.44	1296.84	1303.24	1309.46	1315.68	1321.75	1327.82
595	1270.25	1277.10	1283.80	1290.35	1296.75	1303.15	1309.38	1315.60	1321.68	1327.75
596	1270.14	1277.00	1283.70	1290.26	1296.66	1303.06	1309.29	1315.52	1321.60	1327.68
597	1270.03	1276.90	1283.60	1290.17	1296.57	1302.97	1309.21	1315.44	1321.53	1327.61
598	1269.92	1276.80	1283.50	1290.08	1296.48	1302.88	1309.12	1315.36	1321.45	1327.54
599	1269.81	1276.70	1283.40	1289.99	1296.39	1302.79	1309.04	1315.28	1321.38	1327.47
	.68	.67	.65	.64	.64	.62	.62	.61	.61	.60

#/D	670°
550	1336.65
551	1336.59
552	1336.53
553	1336.47
554	1336.41
555	1336.35
556	1336.29
557	1336.23
558	1336.17
559	1336.11
	.
560	1336.05
561	1335.99
562	1335.92
563	1335.86
564	1335.79
565	1335.73
566	1335.66
567	1335.60
568	1335.53
569	1335.47
	.
570	1335.40
571	1335.33
572	1335.26
573	1335.19
574	1335.12
575	1335.05
576	1334.98
577	1334.91
578	1334.84
579	1334.77
	.
580	1334.70
581	1334.64
582	1334.57
583	1334.51
584	1334.44
585	1334.38
586	1334.31
587	1334.25
588	1334.18
589	1334.12
	.
590	1334.05
591	1333.99
592	1333.92
593	1333.86
594	1333.79
595	1333.73
596	1333.66
597	1333.60
598	1333.53
599	1333.47

TOTAL HEAT OF SUPERHEATED STEAM

ABSOLUTE PRESSURE (TEMPERATURE FAHRENHEIT)

#/□	670°	680°	690°	700°	710°	720°	730°	740°	750°	760°	#/□	
50	1336.65	1342.50	1348.25	1354.00	1359.70	1365.40	1371.05	1376.70	1382.25	1387.80	550	13
51	1336.59	1342.44	1348.20	1353.95	1359.65	1365.35	1371.00	1376.64	1382.20	1387.75	551	13
52	1336.53	1342.38	1348.14	1353.90	1359.60	1365.30	1370.94	1376.58	1382.14	1387.70	552	13
53	1336.47	1342.32	1348.09	1353.85	1359.55	1365.25	1370.89	1376.52	1382.09	1387.65	553	13
54	1336.41	1342.26	1348.03	1353.80	1359.50	1365.20	1370.83	1376.46	1382.03	1387.60	554	13
55	1336.35	1342.20	1347.98	1353.75	1359.45	1365.15	1370.78	1376.40	1381.98	1387.55	555	13
56	1336.29	1342.14	1347.92	1353.70	1359.40	1365.10	1370.72	1376.34	1381.92	1387.50	556	13
57	1336.23	1342.08	1347.87	1353.65	1359.35	1365.05	1370.67	1376.28	1381.87	1387.45	557	13
58	1336.17	1342.02	1347.81	1353.60	1359.30	1365.00	1370.61	1376.22	1381.81	1387.40	558	13
59	1336.11	1341.96	1347.76	1353.55	1359.25	1364.95	1370.56	1376.16	1381.76	1387.35	559	13
		.59	.58	.58	.57	.57	.56	.56	.56	.56		
60	1336.05	1341.90	1347.70	1353.50	1359.20	1364.90	1370.50	1376.10	1381.70	1387.30	560	13
61	1335.99	1341.84	1347.64	1353.44	1359.14	1364.84	1370.45	1376.05	1381.65	1387.25	561	13
62	1335.92	1341.78	1347.58	1353.38	1359.08	1364.78	1370.39	1376.00	1381.60	1387.20	562	13
63	1335.86	1341.72	1347.52	1353.32	1359.02	1364.72	1370.34	1375.95	1381.55	1387.15	563	13
64	1335.79	1341.66	1347.46	1353.26	1358.96	1364.66	1370.28	1375.90	1381.50	1387.10	564	13
65	1335.73	1341.60	1347.40	1353.20	1358.90	1364.60	1370.23	1375.85	1381.45	1387.05	565	13
66	1335.66	1341.54	1347.34	1353.14	1358.84	1364.54	1370.17	1375.80	1381.40	1387.00	566	13
67	1335.60	1341.48	1347.28	1353.08	1358.78	1364.48	1370.12	1375.75	1381.35	1386.95	567	13
68	1335.53	1341.42	1347.22	1353.02	1358.72	1364.42	1370.06	1375.70	1381.30	1386.90	568	13
69	1335.47	1341.36	1347.16	1352.96	1358.66	1364.36	1370.00	1375.65	1381.25	1386.85	569	13
		.59	.58	.58	.57	.57	.56	.56	.56	.56		
70	1335.40	1341.30	1347.10	1352.90	1358.60	1364.30	1369.95	1375.60	1381.20	1386.80	570	13
71	1335.33	1341.23	1347.04	1352.84	1358.54	1364.24	1369.90	1375.55	1381.15	1386.75	571	13
72	1335.26	1341.16	1346.97	1352.78	1358.48	1364.18	1369.84	1375.50	1381.10	1386.70	572	13
73	1335.19	1341.09	1346.91	1352.72	1358.42	1364.12	1369.79	1375.45	1381.05	1386.65	573	13
74	1335.12	1341.02	1346.84	1352.66	1358.36	1364.06	1369.73	1375.40	1381.00	1386.60	574	13
75	1335.05	1340.95	1346.78	1352.60	1358.30	1364.00	1369.68	1375.35	1380.95	1386.55	575	13
76	1334.98	1340.88	1346.71	1352.54	1358.24	1363.94	1369.62	1375.30	1380.90	1386.50	576	13
77	1334.91	1340.81	1346.65	1352.48	1358.18	1363.88	1369.57	1375.25	1380.85	1386.45	577	13
78	1334.84	1340.74	1346.58	1352.42	1358.12	1363.82	1369.51	1375.20	1380.80	1386.40	578	13
79	1334.77	1340.67	1346.52	1352.36	1358.06	1363.76	1369.46	1375.15	1380.75	1386.35	579	13
		.59	.58	.58	.57	.57	.57	.57	.56	.56		
80	1334.70	1340.60	1346.45	1352.30	1358.00	1363.70	1369.40	1375.10	1380.70	1386.30	580	13
81	1334.64	1340.54	1346.39	1352.24	1357.95	1363.65	1369.35	1375.05	1380.65	1386.25	581	13
82	1334.57	1340.48	1346.33	1352.18	1357.89	1363.60	1369.30	1375.00	1380.60	1386.20	582	13
83	1334.51	1340.42	1346.27	1352.12	1357.84	1363.55	1369.25	1374.95	1380.55	1386.15	583	13
84	1334.44	1340.36	1346.21	1352.06	1357.78	1363.50	1369.20	1374.90	1380.50	1386.10	584	13
85	1334.38	1340.30	1346.15	1352.00	1357.73	1363.45	1369.15	1374.85	1380.45	1386.05	585	13
86	1334.31	1340.24	1346.09	1351.94	1357.67	1363.40	1369.10	1374.80	1380.40	1386.00	586	13
87	1334.25	1340.18	1346.03	1351.88	1357.62	1363.35	1369.05	1374.75	1380.35	1385.95	587	13
88	1334.18	1340.12	1345.97	1351.82	1357.56	1363.30	1369.00	1374.70	1380.30	1385.90	588	13
89	1334.12	1340.06	1345.91	1351.76	1357.51	1363.25	1368.95	1374.65	1380.25	1385.85	589	13
		.59	.59	.59	.57	.57	.57	.57	.56	.56		
90	1334.05	1340.00	1345.85	1351.70	1357.45	1363.20	1368.90	1374.60	1380.20	1385.80	590	13
91	1333.98	1339.93	1345.79	1351.64	1357.39	1363.14	1368.84	1374.54	1380.15	1385.75	591	13
92	1333.91	1339.86	1345.72	1351.58	1357.33	1363.08	1368.78	1374.48	1380.09	1385.70	592	13
93	1333.84	1339.79	1345.66	1351.52	1357.27	1363.02	1368.72	1374.42	1380.04	1385.65	593	13
94	1333.77	1339.72	1345.59	1351.46	1357.21	1362.96	1368.66	1374.36	1379.98	1385.60	594	13
95	1333.70	1339.65	1345.53	1351.40	1357.15	1362.90	1368.60	1374.30	1379.93	1385.55	595	13
96	1333.63	1339.58	1345.46	1351.34	1357.09	1362.84	1368.54	1374.24	1379.87	1385.50	596	13
97	1333.56	1339.51	1345.40	1351.28	1357.03	1362.78	1368.48	1374.18	1379.82	1385.45	597	13
98	1333.49	1339.44	1345.33	1351.22	1356.97	1362.72	1368.42	1374.12	1379.76	1385.40	598	13
99	1333.42	1339.37	1345.27	1351.16	1356.91	1362.66	1368.36	1374.06	1379.71	1385.35	599	13
		.60	.59	.59	.58	.58	.57	.57	.56	.56	.56	

TOTAL HEAT OF SUPERHEATED STEAM

ABSOLUTE PRESSURE (TEMPERATURE FAHRENHEIT)

670°	680°	690°	700°	710°	720°	730°	740°	750°	760°
1336.65	1342.50	1348.25	1354.00	1359.70	1365.40	1371.05	1376.70	1382.25	1387.80
1336.59	1342.44	1348.20	1353.95	1359.65	1365.35	1371.00	1376.64	1382.20	1387.75
1336.53	1342.38	1348.14	1353.90	1359.60	1365.30	1370.94	1376.58	1382.14	1387.70
1336.47	1342.32	1348.09	1353.85	1359.55	1365.25	1370.89	1376.52	1382.09	1387.65
1336.41	1342.26	1348.03	1353.80	1359.50	1365.20	1370.83	1376.46	1382.03	1387.60
1336.35	1342.20	1347.98	1353.75	1359.45	1365.15	1370.78	1376.40	1381.98	1387.55
1336.29	1342.14	1347.92	1353.70	1359.40	1365.10	1370.72	1376.34	1381.92	1387.50
1336.23	1342.08	1347.87	1353.65	1359.35	1365.05	1370.67	1376.28	1381.87	1387.45
1336.17	1342.02	1347.81	1353.60	1359.30	1365.00	1370.61	1376.22	1381.81	1387.40
1336.11	1341.96	1347.76	1353.55	1359.25	1364.95	1370.56	1376.16	1381.76	1387.35
.59	.58	.58	.57	.57	.56	.56	.56	.56	.56
1336.05	1341.90	1347.70	1353.50	1359.20	1364.90	1370.50	1376.10	1381.70	1387.30
1335.99	1341.84	1347.64	1353.44	1359.14	1364.84	1370.45	1376.05	1381.65	1387.25
1335.92	1341.78	1347.58	1353.38	1359.08	1364.78	1370.39	1376.00	1381.60	1387.20
1335.86	1341.72	1347.52	1353.32	1359.02	1364.72	1370.34	1375.95	1381.55	1387.15
1335.79	1341.66	1347.46	1353.26	1358.96	1364.66	1370.28	1375.90	1381.50	1387.10
1335.73	1341.60	1347.40	1353.20	1358.90	1364.60	1370.23	1375.85	1381.45	1387.05
1335.66	1341.54	1347.34	1353.14	1358.84	1364.54	1370.17	1375.80	1381.40	1387.00
1335.60	1341.48	1347.28	1353.08	1358.78	1364.48	1370.12	1375.75	1381.35	1386.95
1335.53	1341.42	1347.22	1353.02	1358.72	1364.42	1370.06	1375.70	1381.30	1386.90
1335.47	1341.36	1347.16	1352.96	1358.66	1364.36	1370.00	1375.65	1381.25	1386.85
.59	.58	.58	.57	.57	.56	.56	.56	.56	.56
1335.40	1341.30	1347.10	1352.90	1358.60	1364.30	1369.95	1375.60	1381.20	1386.80
1335.33	1341.23	1347.04	1352.84	1358.54	1364.24	1369.90	1375.55	1381.15	1386.75
1335.26	1341.16	1346.97	1352.78	1358.48	1364.18	1369.84	1375.50	1381.10	1386.70
1335.19	1341.09	1346.91	1352.72	1358.42	1364.12	1369.79	1375.45	1381.05	1386.65
1335.12	1341.02	1346.84	1352.66	1358.36	1364.06	1369.73	1375.40	1381.00	1386.60
1335.05	1340.95	1346.78	1352.60	1358.30	1364.00	1369.68	1375.35	1380.95	1386.55
1334.98	1340.88	1346.71	1352.54	1358.24	1363.94	1369.62	1375.30	1380.90	1386.50
1334.91	1340.81	1346.65	1352.48	1358.18	1363.88	1369.57	1375.25	1380.85	1386.45
1334.84	1340.74	1346.58	1352.42	1358.12	1363.82	1369.51	1375.20	1380.80	1386.40
1334.77	1340.67	1346.52	1352.36	1358.06	1363.76	1369.46	1375.15	1380.75	1386.35
.59	.58	.58	.57	.57	.57	.57	.56	.56	.56
1334.70	1340.60	1346.45	1352.30	1358.00	1363.70	1369.40	1375.10	1380.70	1386.30
1334.64	1340.54	1346.39	1352.24	1357.95	1363.65	1369.35	1375.05	1380.65	1386.25
1334.57	1340.48	1346.33	1352.18	1357.89	1363.60	1369.30	1375.00	1380.60	1386.20
1334.51	1340.42	1346.27	1352.12	1357.84	1363.55	1369.25	1374.95	1380.55	1386.15
1334.44	1340.36	1346.21	1352.06	1357.78	1363.50	1369.20	1374.90	1380.50	1386.10
1334.38	1340.30	1346.15	1352.00	1357.73	1363.45	1369.15	1374.85	1380.45	1386.05
1334.31	1340.24	1346.09	1351.94	1357.67	1363.40	1369.10	1374.80	1380.40	1386.00
1334.25	1340.18	1346.03	1351.88	1357.62	1363.35	1369.05	1374.75	1380.35	1385.95
1334.18	1340.12	1345.97	1351.82	1357.56	1363.30	1369.00	1374.70	1380.30	1385.90
1334.12	1340.06	1345.91	1351.76	1357.51	1363.25	1368.95	1374.65	1380.25	1385.85
.59	.59	.59	.57	.57	.57	.57	.56	.56	.56
1334.05	1340.00	1345.85	1351.70	1357.45	1363.20	1368.90	1374.60	1380.20	1385.80
1333.98	1339.93	1345.79	1351.64	1357.39	1363.14	1368.84	1374.54	1380.15	1385.75
1333.91	1339.86	1345.72	1351.58	1357.33	1363.08	1368.78	1374.48	1380.09	1385.70
1333.84	1339.79	1345.66	1351.52	1357.27	1363.02	1368.72	1374.42	1380.04	1385.65
1333.77	1339.72	1345.59	1351.46	1357.21	1362.96	1368.66	1374.36	1379.98	1385.60
1333.70	1339.65	1345.53	1351.40	1357.15	1362.90	1368.60	1374.30	1379.93	1385.55
1333.63	1339.58	1345.46	1351.34	1357.09	1362.84	1368.54	1374.24	1379.87	1385.50
1333.56	1339.51	1345.40	1351.28	1357.03	1362.78	1368.48	1374.18	1379.82	1385.45
1333.49	1339.44	1345.33	1351.22	1356.97	1362.72	1368.42	1374.12	1379.76	1385.40
1333.42	1339.37	1345.27	1351.16	1356.91	1362.66	1368.36	1374.06	1379.71	1385.35
.60	.59	.59	.58	.58	.57	.57	.56	.56	.56

#/□	770°	780°	7
550	1393.35	1398.90	14
551	1393.30	1398.85	14
552	1393.24	1398.80	14
553	1393.19	1398.75	14
554	1393.13	1398.70	14
555	1393.08	1398.65	14
556	1393.02	1398.60	14
557	1392.97	1398.55	14
558	1392.91	1398.50	14
559	1392.86	1398.45	14
	.56	.55	
560	1392.80	1398.40	14
561	1392.76	1398.36	14
562	1392.72	1398.32	14
563	1392.68	1398.28	14
564	1392.64	1398.24	14
565	1392.60	1398.20	14
566	1392.56	1398.16	14
567	1392.52	1398.12	14
568	1392.48	1398.08	14
569	1392.44	1398.04	14
	.56	.55	
570	1392.40	1398.00	14
571	1392.35	1397.95	14
572	1392.30	1397.90	14
573	1392.25	1397.85	14
574	1392.20	1397.80	14
575	1392.15	1397.75	14
576	1392.10	1397.70	14
577	1392.05	1397.65	14
578	1392.00	1397.60	14
579	1391.95	1397.55	14
	.56	.56	
580	1391.90	1397.50	14
581	1391.85	1397.45	14
582	1391.80	1397.40	14
583	1391.75	1397.35	14
584	1391.70	1397.30	14
585	1391.65	1397.25	14
586	1391.60	1397.20	14
587	1391.55	1397.15	14
588	1391.50	1397.10	14
589	1391.45	1397.05	14
	.56	.56	
590	1391.40	1397.00	14
591	1391.35	1396.95	14
592	1391.30	1396.90	14
593	1391.25	1396.85	14
594	1391.20	1396.80	14
595	1391.15	1396.75	14
596	1391.10	1396.70	14
597	1391.05	1396.65	14
598	1391.00	1396.60	14
599	1390.95	1396.55	14
	.56	.56	

780°	790°	800°	810°	820°	830°	840°	850°	860°
1398.90	1404.40	1409.90	1415.36	1420.82	1426.28	1431.74	1437.20	1442.62
1398.85	1404.35	1409.85	1415.31	1420.77	1426.24	1431.70	1437.16	1442.58
1398.80	1404.30	1409.80	1415.26	1420.73	1426.19	1431.66	1437.12	1442.54
1398.75	1404.25	1409.75	1415.22	1420.68	1426.15	1431.61	1437.08	1442.50
1398.70	1404.20	1409.70	1415.17	1420.64	1426.10	1431.57	1437.04	1442.46
1398.65	1404.15	1409.65	1415.12	1420.59	1426.06	1431.53	1437.00	1442.42
1398.60	1404.10	1409.60	1415.07	1420.54	1426.02	1431.49	1436.96	1442.38
1398.55	1404.05	1409.55	1415.02	1420.50	1425.97	1431.45	1436.92	1442.34
1398.50	1404.00	1409.50	1414.98	1420.45	1425.93	1431.40	1436.88	1442.30
1398.45	1403.95	1409.45	1414.93	1420.41	1425.88	1431.36	1436.84	1442.26
.55	.55	.55	.55	.55	.55	.55	.54	.54
1398.40	1403.90	1409.40	1414.88	1420.36	1425.84	1431.32	1436.80	1442.22
1398.36	1403.86	1409.36	1414.84	1420.32	1425.80	1431.28	1436.76	1442.18
1398.32	1403.82	1409.32	1414.80	1420.28	1425.76	1431.24	1436.72	1442.14
1398.28	1403.78	1409.28	1414.76	1420.24	1425.72	1431.20	1436.68	1442.11
1398.24	1403.74	1409.24	1414.72	1420.20	1425.68	1431.16	1436.64	1442.07
1398.20	1403.70	1409.20	1414.68	1420.16	1425.64	1431.12	1436.60	1442.03
1398.16	1403.66	1409.16	1414.64	1420.12	1425.60	1431.08	1436.56	1441.99
1398.12	1403.62	1409.12	1414.60	1420.08	1425.56	1431.04	1436.52	1441.95
1398.08	1403.58	1409.08	1414.56	1420.04	1425.52	1431.00	1436.48	1441.92
1398.04	1403.54	1409.04	1414.52	1420.00	1425.48	1430.96	1436.44	1441.88
.55	.55	.55	.55	.55	.55	.55	.54	.54
1398.00	1403.50	1409.00	1414.48	1419.96	1425.44	1430.92	1436.40	1441.84
1397.95	1403.46	1408.96	1414.44	1419.92	1425.40	1430.88	1436.36	1441.80
1397.90	1403.41	1408.92	1414.40	1419.88	1425.36	1430.84	1436.32	1441.76
1397.85	1403.37	1408.88	1414.36	1419.84	1425.32	1430.80	1436.28	1441.72
1397.80	1403.32	1408.84	1414.32	1419.80	1425.28	1430.76	1436.24	1441.68
1397.75	1403.28	1408.80	1414.28	1419.76	1425.24	1430.72	1436.20	1441.64
1397.70	1403.23	1408.76	1414.24	1419.72	1425.20	1430.68	1436.16	1441.60
1397.65	1403.19	1408.72	1414.20	1419.68	1425.16	1430.64	1436.12	1441.56
1397.60	1403.14	1408.68	1414.16	1419.64	1425.12	1430.60	1436.08	1441.52
1397.55	1403.10	1408.64	1414.12	1419.60	1425.08	1430.56	1436.04	1441.48
.56	.56	.55	.55	.55	.55	.55	.54	.54
1397.50	1403.05	1408.60	1414.08	1419.56	1425.04	1430.52	1436.00	1441.44
1397.45	1403.00	1408.55	1414.03	1419.51	1425.00	1430.48	1435.96	1441.40
1397.40	1402.95	1408.50	1413.98	1419.47	1424.95	1430.44	1435.92	1441.36
1397.35	1402.90	1408.45	1413.94	1419.42	1424.91	1430.39	1435.88	1441.33
1397.30	1402.85	1408.40	1413.89	1419.38	1424.86	1430.35	1435.84	1441.29
1397.25	1402.80	1408.35	1413.84	1419.33	1424.82	1430.31	1435.80	1441.25
1397.20	1402.75	1408.30	1413.79	1419.28	1424.78	1430.27	1435.76	1441.21
1397.15	1402.70	1408.25	1413.74	1419.24	1424.73	1430.23	1435.72	1441.17
1397.10	1402.65	1408.20	1413.70	1419.19	1424.69	1430.18	1435.68	1441.14
1397.05	1402.60	1408.15	1413.65	1419.15	1424.64	1430.14	1435.64	1441.10
.56	.56	.55	.55	.55	.55	.55	.55	.55
1397.00	1402.55	1408.10	1413.60	1419.10	1424.60	1430.10	1435.60	1441.06
1396.95	1402.51	1408.06	1413.56	1419.06	1424.56	1430.06	1435.56	1441.02
1396.90	1402.46	1408.02	1413.52	1419.02	1424.52	1430.02	1435.52	1440.98
1396.85	1402.42	1407.98	1413.48	1418.98	1424.48	1429.98	1435.48	1440.94
1396.80	1402.37	1407.94	1413.44	1418.94	1424.44	1429.94	1435.44	1440.90
1396.75	1402.33	1407.90	1413.40	1418.90	1424.40	1429.90	1435.40	1440.86
1396.70	1402.28	1407.86	1413.36	1418.86	1424.36	1429.86	1435.36	1440.82
1396.65	1402.24	1407.82	1413.32	1418.82	1424.32	1429.82	1435.32	1440.78
1396.60	1402.19	1407.78	1413.28	1418.78	1424.29	1429.78	1435.28	1440.74
1396.55	1402.15	1407.74	1413.24	1418.74	1424.24	1429.74	1435.24	1440.70
.56	.56	.55	.55	.55	.55	.55	.55	.55

ENTHALPY OF SUPERHEATED STEAM.

By Fred J. Wiegand.*

One of the most frequent uses made of a steam table is to find the enthalpy, or total heat, of superheated steam. For pressures above 250 pounds, the ordinary tables require a double interpolation as the values are given only in increments of five or ten pounds pressure and ten, twenty, or more degrees temperature. To avoid these laborious interpolations with their attendant chances of error, the accompanying table has been compiled from which enthalpy may be read with but one calculation involving merely the multiplication of two small numbers. The values of enthalpy are given in B. T. U. per pound of steam in increments of one pound pressure and ten degrees temperature. It is believed that the range of pressure and temperature selected will make the table useful to personnel concerned with the latest type of boilers.

The tables are constructed in the following manner. At the end of each group of ten pounds pressure and between the temperature columns, there is shown a proportional part representing the increase in enthalpy for one degree increase in temperature. These proportional parts or factors have been worked out based on the average variation over a ten-degree range of temperature and a ten-pound range of pressure. The example below illustrates a use of the table.

Supposing it is desired to find the enthalpy of steam at a pressure of 577 pounds per square inch (absolute) and a temperature of 625.6 degrees (F.). Opposite the pressure 577 and in the column headed 620 degrees, the enthalpy is given as 1304.64 B.T.U. per pound. To this must be added the enthalpy represented by 5.6 degrees at the given pressure, so reference is made to

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the factor at the end of the 570-pound group, *i. e.*, between 579 and 800 pound pressure, and between the 620 degree and 630 degree columns. We find .62 and multiply it by 5.6, obtaining a product of 3.47. Adding this to 1304.64, the value of enthalpy required is 1308.11 B.T.U. per pound. In the event that the pressure is given to a fraction of a pound, values between those shown in the table for the even pounds can be interpolated mentally by reason of the fact that the change in enthalpy is very small for a pressure difference of one pound, especially at elevated temperatures. It can be neglected for most practical purposes.

The values are based on the 1936 steam tables of Joseph H. Keenan and Frederick G. Keyes, published by John Wiley & Sons, Inc.

DISCUSSIONS AND COMMENTS.

STOPPING AND BACKING TESTS—U. S. COAST GUARD CUTTERS *DUANE* AND *CAMPBELL*.

(SEE PAGE 465, NOVEMBER, 1938, JOURNAL.)

REAR ADMIRAL SAMUEL M. ROBINSON, U. S. NAVY.—Commander Curry's article covering backing tests on the Coast Guard Cutters *Duane* and *Campbell* is an excellent one. It furnishes much data for the use of engineers who are faced with making the necessary compromises in the case of backing turbines. It also points out very clearly the necessity for reducing the time for operating the maneuvering throttles. It also makes very clear what the effect of modern high-speed turbines is on backing and shows how they have added to the backing time and headreach and shows that large reverse torque during the period of reversing the turbines is of great importance.

There are many other points brought out in this paper, but these seem to be the salient ones.

In making use of these data, marine engineers should, however, keep in mind that some of these points apply specially and particularly to small vessels, such as a Coast Guard cutter or a destroyer. They will not have nearly the same relative effect on such vessels as battleships or aircraft carriers, where the total time required for stopping is much greater.

There is one point in regard to reversing propellers which the author says puzzles him. The puzzling point is: The claim has been made that the negative peak torque during reversal occurs somewhere around 35 per cent full ahead R.P.M. and amounts to about 90 per cent full ahead torque. The author gives an example to show how this would require "super-intelligent" propellers. First, let me say that there can scarcely be any doubt as to this point, since it has been verified by numberless tests, both here and

abroad, and on both full-sized propellers and on models. The trouble is that there is an "understood," but not stated, assumption that goes with this particular phenomenon. It is assumed that only propellers suitable for any particular type of propelling duty will be used. The propellers for the two types of ships indicated by the author would be entirely different from each other. It is not sufficient to define a propeller only by giving its pitch and diameter. Further, it must be understood that the figures given are not exact. It would probably be more accurate to say the maximum point occurs between 30 and 40 per cent and is between 90 and 100 per cent. Even these limits might not cover all cases, but they will certainly cover the vast majority of them.

It is to be hoped that the author will continue his studies on this subject. It is a difficult one, at best, because of the great amount of data that must be taken to render any backing data valuable and requires much patience on the part of the investigator, and the author is to be congratulated on the thoroughness with which he has covered his subject.

CAPTAIN LYBRAND P. SMITH, U. S. NAVY.—Commander Curry has presented a valuable and interesting paper which deserves thorough study and should stimulate further experiment with actual ships under more favorable conditions than those which confronted him.

He makes a tentative conclusion that the time interval between giving an astern bell and bringing the vessel to a relatively slow speed "is practically the same with one or both nozzle groups in use * * *." While this conclusion is only tentative, it should be checked thoroughly on various types of ships, since it may indicate that we are providing more astern power than our propellers can possibly absorb during reversal. Should this finding be confirmed, then in most cases we would be justified in installing astern turbines with only enough power to give whatever *steady* astern speed is desired.

Several clerical errors were noted which might cause some confusion. In the formula for force at top of page 471 a delta (δ) should appear before the first V; and a decimal point should be

inserted in the numeral representing gravitational acceleration. In the formula for distance at bottom of same page, t should be inserted after Vo. Several times acceleration is erroneously given as " feet per second " instead of " feet per second per second " or " feet per second ^{2}."

The inference that great cavitation occurs during reversal is verified by experiment. Commander Dodson (1)* presented excellent photographs of a propeller acting as a brake, which show violent cavitation. Because of such cavitation propeller curves obtained under non-cavitating conditions, such as Figure 2 in the present paper, are not reliable for the violent conditions during reversal, but only for steady advance before cavitation sets in.

In this connection, if Comdr. Curry's torque and revolution data are re-plotted to give torque *vs* R.P.M. curves they generally have a shape similar to the torque *vs* R.P.M. curves for a high speed vessel presented by Comdr. Dodson. (2)*

Comdr. Curry should be complimented on stating so clearly when and where his data are doubtful and showing that the principal use of tentative conclusions from such data is to serve as a guide for future experiment which it is hoped his paper will stimulate.

A study of the present paper shows that before we can relate model propeller data to full size ship data *for conditions of reversing* we must first solve two other problems.

Our model propeller data are taken at various speeds of advance. This advance is relative to the water in which the propeller works. Behind a model hull or a real hull the " wake " is the water in which the propeller works. For steady propulsion we have enough knowledge of the wake to predict from a model the performance of a full size ship. But knowledge of wake during the churned up conditions of reversing is practically nil. Until we obtain such knowledge, model propeller curves, even those obtained under cavitating conditions, are of little value for predicting reversal performance.

The other problem is this: What is the significance of a torsion meter reading *during acceleration?* Under steady conditions the significance of a torsion meter reading is very clear. It represents

* Numbers in parentheses refer to bibliography following this discussion.

the torque in a certain length of shaft; which in turn (neglecting bearing friction) represents the torque supplied by the turbine and resisted by the propeller. But during positive or negative acceleration energy is being put into or given up by rotating masses. The torsion meter readings still represent the torque in the same length of shaft; but now this does *not* represent either the turbine torque or the propeller torque, which are the two torques of primary interest. This one question regarding torsion meters would merit a separate paper by a capable mathematical physicist.

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R. H. TINGEY, TECHNICAL AND DESIGN DEPARTMENT, BETHLEHEM SHIPBUILDING CORPORATION, LTD.—I would like to make the following comments on the article entitled "Stopping and Backing Tests—U. S. Coast Guard Cutters *Duane* and *Campbell*" by Lieutenant Commander H. H. Curry, U. S. C. G., in the November issue of the JOURNAL.

The test data on the stopping and backing of ships presented in this article will be of inestimable value to engineers concerned with the stopping problem. The results appear to be remarkably consistent, considering the difficulties of coordinating many measurements over such a short period of time, and they should serve as a sound basis from which conclusions can be drawn. However, I believe that some of the conclusions drawn by the author are open to question.

The author of the article concludes that the conventional type of manually operated throttle cannot be manipulated fast enough for a satisfactory crash stop and should be replaced by a hydraulic type of maneuvering gear. In my opinion this would be an unnecessary and undesirable complication that should be avoided.

The article states that with manually operated throttles a period of 20 seconds elapses between the time the full astern bell is received and the time the full astern steam chest pressure is attained. This time seems to be excessive since it has rarely exceeded 10 seconds on ships with which I am acquainted and is often about 8 seconds. With reasonably easy acting operating gear, the throttle man can spin the ahead throttle closed without much effort. Then he needs to open the astern throttle only about one quarter of its lift to obtain practically full steam flow. As can be visualized readily, these operations can be performed in considerably less than 20 seconds.

The excessive time to operate these throttles is reflected in the measured time to stop the shafts. On those tests where the throttles were operated normally (that is where the ahead throttle was closed before the astern was opened) the time to stop was about 45 seconds. However, judging by our own experience, this time should be not over 30 seconds and probably the difference is due largely to speed of throttle operation. All types of ships from tankers to destroyers perform a routine crash stop on trials and the time to stop the shaft does not as a rule exceed 30 seconds.

Furthermore in a number of these stops, with which I am familiar, the astern throttle was not opened up quite as quickly as it could have been. This shows that speed of operation of the throttle is not a serious limitation since a satisfactory time to stop was obtained without using the maximum rate of opening. The throttle man usually has the operating engineer's instinct to avoid unnecessary abuse of his engines and so tends to "nurse" the astern throttle a little while stopping and will not throw it wide open instantly. However, on some tests where particular attention was paid to speed, the shafts stopped in 20 seconds. All of these turbines incorporated not more than the normal number and size of astern elements, similar to the Cutters, and in some cases they had less.

The author's argument that speed of operation of throttle is important does not apply with as much force to a heavy ship as it does to a light one. In the case of a comparatively light ship like the Coast Guard Cutters, the time to operate the throttles (10 to 20 secs.) would be about 10 to 20 per cent of the time to stop the

ship dead in the water (1 min. 50 secs.). This is a considerable portion of the total stopping time and, as the author points out, it is very important in its effect on head reach because it comes at a period when the ship is traveling full speed. However, the time to stop a heavy ship is considerably longer i. e. about 4 minutes. The time to operate the throttles remains the same (10 to 20 seeconds) but is only 5 to 10 per cent of the stopping time and therefore is relatively less important. On an ordinary merchant ship the speed of operation of the throttles has only a minor influence on the stopping time and there is no need for hydraulically operated gears. On a naval ship speed of operation is of some more importance, but even here, the added complication of hydraulic gear is not justified by the reduction in stopping time obtained.

In the article it is suggested that more astern torque be provided to be used in the early stages of the maneuver to stop the shaft and accelerate it astern quicker. This would bring the full stopping effect of the propeller into play earlier and so reduce the stopping time. The value of this change also would be less in a heavy ship whose stopping time is larger than a light ship. The gain in time would be the same in both cases, but it would be a smaller percentage of the total stopping time in the case of the heavy ship. In fact, the time to stop the shaft is already so small in relation to the total stopping time of a merchant ship that little can be gained by any such change.

The form of specification for an astern turbine proposed by the author is essentially sound. The astern turbine should be capable of stopping the shaft in a specified time, say 30 seconds, and the astern running conditions after a steady state has been reached should also be specified. The author has used R.P.M. to define the steady state, but I believe S.H.P. would be found more satisfactory from a practical standpoint. However, in any ship with which I am familiar, the specification of time to stop the shaft would be found redundant because any astern turbine that will meet the usual steady state requirements of power of revolutions will be able to stop the shaft in 30 seconds. As the author states, power to give about 10 to 12 knots astern is sufficient in the usual case. A two stage astern turbine consisting of a three row impulse wheel

followed by a two row wheel will meet these conditions easily. If higher blade speeds are used a two row and a single row will suffice. The provision of more astern turbine elements unnecessarily handicaps the turbine design and will ultimately show up as a loss in efficiency when running ahead.

LIEUTENANT COMMANDER H. H. CURRY, U. S. COAST GUARD.—Reply to comments on "Stopping and Backing Tests, U. S. Coast Guard Cutters *Duane* and *Campbell*."

I am in complete agreement with the comments of Captain Smith that results of model propeller tests are of little value in predicting performance during reversal, especially on high-speed hulls whose propellers are approaching a cavitating condition in normal full-speed operation as indicated by Lerbs (3) * or Eggerts formula (4),* and that accurate full scale tests are needed. The paper was written not so much to present the data obtained as to outline the method used in attacking the problem and in hope of stimulating more accurate and complete tests, as I do not feel that the results obtained are sufficiently conclusive or complete to warrant definite conclusions.

In regard to the question of torsion meter readings during deceleration, the low rate of change of R.P.M., say .1 revolution per second per second, together with the estimated wr^2 of shafting aft of torsion meter and of propeller (around 13,000 foot^2 pounds) gives a small correction to apply to torsion meter readings to correct for deceleration of rotating masses aft of torsion meter and to obtain actual torque at propeller surface.† Of course when an

* Numbers in parentheses refer to bibliography following this discussion.

† Example.—Propeller weighs 3600 pounds, radius of gyration equals 21.5 inches. Shafting aft of torsionmeter weighs 17,350 pounds, radius of gyration 3.5 inches.

Moment of inertia of propeller $\frac{3600 \times 21.5^2}{32.17 \times 12}$ equals 359 slug feet^2.

Moment of inertia of shaft equals..... 42 slug feet^2.

Total moment of inertia..... 401 slug feet^2.

Torque in foot-pounds equals moment of inertia (I) in slug feet^2, or $\frac{wk^2}{g}$, times angular deceleration in radians per second per second.

Assume deceleration (α) is from 240 R.P.M. to 0 R.P.M. in 40 seconds, or at the rate of 6 R.P.M. per second or 0.1 revolutions per second^2, or 0.2π radians per second^2.

Thus torque ($I \times \alpha$) equals $401 \times .2\pi = 252$ foot-pounds.

Designated speed torque (3100 H.P. at 254 R.P.M.) is 64,000 foot-pounds.

Hence, per cent of designated torque used in deceleration of revolving masses aft of torsionmeter equals $\frac{252}{64,000}$ or 0.393 of 1 per cent.

attempt is made to obtain torque under such conditions from electrical readings of a turbo-electric plant the correction would be much larger as the wr^2 of motor would be several times that of the corresponding propeller. In such tests of turbo-electric machinery as I have studied, negative accelerations were also much higher than obtained on these tests. The correction for wr^2 deceleration would apparently be still higher in going from astern torque at astern turbine blades to astern torque at propeller of a double reduction geared turbine plant.

Perhaps Mr. Tingey's defense of manually operated maneuvering valves is warranted, as I have operated several older direct connected turbine driven destroyers where this type of valve gave entirely satisfactory results as far as speed in maneuvering was concerned, however, they were easier to operate and much faster than the valves on the cutters in question. Each maneuvering valve on the cutters operated through shafting, universal joints, and two sets of gears. An attempt was made in the original article to stress the obvious and unquestioned point that those first 10 or 15 seconds are of more importance in reducing head reach and probable damage from a collision occurring a moment later than they are in reducing the comparatively unimportant factor time to dead in water.

I do not wish to be understood as believing that high revolutions astern while hull is travelling at a fair speed ahead will necessarily reduce hull speed faster than a lower astern R.P.M. under these conditions of great cavitation. There is no question in my mind but that less delay and greater deceleration down to the point where a fair astern torque is being developed at propeller surface must appreciably reduce head reach and make a safer ship in so far as safety is influenced by time required to decelerate hull to say half speed in a high-speed vessel. I agree with Mr. Tingey that as the displacement to power ratio and stopping time increases the importance of maneuvering gear delay decreases.

It appears to me to be a debatable question whether or not hydraulic gear does represent an appreciable complication on higher powered vessels if some method of automatically stopping in case of low lubricating oil pressure is required.

If it is agreed that a steady astern speed of 10 or 12 knots is sufficient then S.H.P. astern as a per cent of full ahead power must vary widely with hull and propeller design and speed length ratio. Either S.H.P. or R.P.M. astern would apparently be a satisfactory specification as in any case both torque and R.P.M. should be determined for actual design, but R.P.M. was proposed as being a factor which could be selected early in preliminary design and which could always be accurately measured on trial while means of measuring S.H.P. astern is not always available. My personal preference would be to specify as far as practicable only factors which influence final performance and which can be accurately measured on trial runs to determine if specifications have been met. In some cases there might be a psychological advantage in specifying astern R.P.M. instead of power as the required astern power might appear to some types of practical marine men as a shockingly small per cent of full power in small high speed-length ratio hulls.

It might be of interest to add that one of the cutters was operated astern over the Rockland mile at 14.1 knots at 201.6 R.P.M. as a mean of several runs. This R.P.M. corresponds to about 17 knots ahead. Unfortunately no means of measuring torque was available.

It is with the greatest hesitation that I express an opinion which appears to conflict with those of such a recognized authority as Admiral Robinson; but I feel that accurate full scale tests on comparatively high-powered and high-speed hulls, where hull speed does not remain even approximately constant, but must fall rapidly due to higher hull resistance per ton of displacement, and recording electrical data as oscilograms rather than attempting to read the highly damped instruments regularly installed, and correcting results for wr^2 of rotating masses, will show a negative torque hump of much less than 90 per cent before propeller passes through zero speed. I would not presume to question his data on lightly loaded propellers at slow hull speeds, but I have maneuvered a comparatively low-power synchronous motor driven Coast Guard cutter which was designed to have 240 volts applied to generator field to obtain sufficient reversing torque, with only 110 volts on the generator field in the induction and synchronizing positions and

on reversing from a steady hull speed of about ⅔ full speed found no very noticeable change in performance over using the designed 240 volts on generator field. At higher hull speeds I reached the opinion that what was needed was not more braking torque to stop motor before zero R.P.M. was reached, but more torque at higher astern speeds up near pull in point. These tests were roughly qualitative only to satisfy my own curiosity and are not to be taken too seriously, but do in my opinion indicate the need of accurate full-scale tests, for should these impressions be correct, designers may be needlessly handicapping the synchronous turbo-electric drive by building in high reversing torque to get over an exaggerated or imaginary hump, especially in those types of hulls where weight is of major importance. I understand that this maneuvering condition rather than full speed performance may determine weight.

The assumed conditions intended to demonstrate why propeller design would apparently influence peak torques were rather extreme, but still vessels have been built with propellers operating under such conditions. I feel that speed of advance of propeller through the water and submergence must also influence peak torques during maneuvering by changing cavitating conditions and circulation.

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CRACK DETECTION IN TURBINE BLADES.

Turbine blades are subjected to forces which defy complete analysis. Their contours promote failure by progressive cracking. The following article describes the use of the Magnaflux process in detecting fatigue cracks when invisible in their early stages. The article is by T. C. Rathbone, Chief Engineer, Turbine Division, Fidelity and Casualty Company of New York. It was published in the November, 1938, issue of "Power," New York, N. Y.

Costly turbine wrecks occur when blade cracks progress to failure. Various methods have been used in attempting to discover cracks in their early stages. Turbines have thousands of blades, making the "whiting" test tedious and unsatisfactory. Detection of cracks by change in vibration frequency also has proved unreliable, due to differences between blades and buckets occasioned by non-uniformity in root fastening, section and shrouding. Also, for this method, cracks have to be developed to the extent of appreciably changing the section modulus of the blade.

Detecting cracks by change in the sound or "ring" when the blade or other part is struck a blow is not reliable. Broken lashing wires can be readily found in this manner, and occasionally well-developed cracks. But incipient cracks do not alter the tone sufficiently for detection. In one case, a disk wheel with a crack extending nine inches from the rim gave a clearer tone than other flawless disks.

Visual inspection, even with suitable lights, mirrors and careful cleaning of all surfaces, can not be depended upon. Some attempts have been made to heat the blades moderately with a torch, watching for an abrupt change in the characteristic oxide colors at a crack. Pickling to etch the crack is obviously to be discouraged. Of course, magnetic test methods are not applicable to non-ferrous blading. However, steel-alloy blades have become so prevalent that magnetic testing for cracks is widely used.

One magnetic method (the Magnaflux process) depends for its effectiveness on the tendency of fine magnetic powder to adhere to the line of an otherwise invisible crack when the part is properly magnetized. Adherence of the powder exhibits the crack so conspicuously as to be noticeable from a distance of several feet. In principle, flux lines are forced into the air by the crack and the magnetic powder tends to bridge the path.

This phenomenon was first reported by Major W. E. Hoke, who observed the collection of fine iron particles at surface cracks while lapping with the magnetic chuck. Dr. A. V. De Forest adapted the principle to practical use. First attempts employed a type of fluxmeter which, when moved along the surface, would indicate the presence of a flaw by a sudden change in field density. This method is still very useful for certain inspections.

Turbine manufacturers applied magnetic powder to turbine parts in this country about a decade ago. At that time Westinghouse became interested in the process in the attempt to determine which blades in a damaged row were salvageable, as well as in crack detection generally.

Non-ferrous tanks were built large enough to accommodate all turbine blades, with adjustable electro-magnets immediately beneath. The powder used was the magnetic oxide (Fe_3O_4) maintained in suspension in an oil bath by agitation.

In practice, the blade was immersed in the bath, magnetized, taken out and drained, and examined for the tell-tale line of black oxide, much the same as used today for routine inspection in mass production of a variety of products. Even then the importance of flux direction was recognized, as these early tanks were provided with sets of magnets for cross-magnetizing as well as setting up flux in the longitudinal direction, to exhibit longitudinal "folds" as well as transverse cracks.

This apparatus was sent to various power plants but was suitable only for individual blades, removed from the rotor. Additional advantage from testing blades assembled in the rotor was early apparent. Some difficulty was experienced in applying a film with the oxide in suspension, and the powder obtainable then did not dust satisfactorily. It was dry metallic powder made in the laboratory by filing or grinding a piece of cast iron, a tedious process yielding coarse powder.

TESTING ASSEMBLED BLADES.

To magnetize assembled blades, electromagnets were made in the laboratory to be held at blade tips, setting up a flux path in the longitudinal direction, at right angles to the position of expected blade cracks. The first tests were made on blades assembled in a rotor segment undergoing fatigue tests in the vibrating machine.

These developments were in progress in 1929, about the time when Dr. De Forest brought out the present dry Magnaflux powder. Very finely divided iron particles are coated with an inert oxide preparation to prevent cohesion, increase the mobility of the powder, and facilitate dry dusting. This powder, greyish white, sharply contrasting with usual dark surfaces of parts in service, has made practical the application of the process to all kinds of parts without disassembly. The method is particularly applicable to blading.

The process is controlled by the Magnaflux Corp., who license users. Its use is well established in automotive and manufacturing fields for parts in production. Much of the practical field-development work in dry-powder testing of turbine blades and parts has been carried out by the author's company whose licenses permit use of the process on turbine blading as well as other apparatus. As these licenses are limited to the company's insurance inspection activities only, increasing demand for blade testing is being met by a field inspection service of the Magnaflux Corp.

CLEANING.

Experience has shown that scrupulous cleaning of the surfaces is not necessary; the powder collects readily over cracks covered with thin light scale or oxide. Well-developed cracks can usually be exhibited under a piece of heavy paper. Thick, loose deposits should be removed by wire brushing, scraping, flyash blasting or other means. Oily deposits should be cleaned with a solvent. When the dusting method is used, the surface must be dry, so that the powder is free to move.

Several methods for dusting on the powder have been used, ranging from a salt shaker or a sack of powder on a stick, to various types of sprays. To cover inaccessible surfaces presented by close rows of blading, a common spray bulb with a non-ferrous nozzle (such as is used for sprinkling laundry) has been found satisfactory, especially after a technique of combined throwing and squeezing has been developed. Very little powder is necessary to get effective results. Spraying great clouds of powder with a pump-gun spray is not only ineffective, but messy and wasteful. Tapping the blades lightly assists the powder to collect at a crack.

The important thing is to insure covering critical areas, and some knowledge of blade failure types is essential. Cracks are prone to occur in definite localities. Cracks flush with the blade root are hard to detect, the powder naturally collecting at this junction, as it is a crack so far as the powder is concerned. Cracks one-half to one inch above the root occur on certain types of blading having root "reinforcement." They start usually at the inlet edge. Next, cracks are likely to occur at lashing-wire holes, extending both ways,

and some care is required here, as a heavy silver solder fillet may mask part of the crack.

Other types of cracks occur in thin exit edges of reaction blades, usually opposite lashing wires. These may not always be due to simple fatigue and their location may have no relation to points of stress concentration for the several vibration modes. Cracks are also prone to occur at sharp nicks produced mechanically or by corrosion and erosion. An isolated nick is more serious than an edge rough throughout its length. Representative cracks are exhibited by the powder. This powder cannot readily be blown off by the breath, and is thus distinguishable from powder held mechanically, as in a ledge or scratch. Small mirrors of the dental type, on extension handles, and small lights which can be inserted between rows are a valuable aid in detection.

THREE METHODS.

In general, ferrous parts are magnetized by three methods: (1) passing current directly through the part, (2) by applying permanent magnets, or electromagnets, and (3) by winding energized cables around the object. W. K. Crawford,[1] while associated with Dr. De Forest, in 1930, used the "wrapping" method on a great variety of apparatus parts, car wheels, etc. Later, E. G. Campbell,[2] F. Jacobs,[3] and H. Johnson[4] experimented with methods of wrapping turbine rotors to magnetize the blading, and established a fairly successful inspection procedure.

Several methods of magnetizing blades and buckets assembled in the rotor have been employed in recent years. By one method, magnetizing one or several complete rows at a time is attempted by wrapping the rotor body with cables carrying current supplied by a portable welding set, using from 500 to 2000 or more ampere-turns. The detail of locating these coils, and the direction of wrapping vary among different users.

Our own experience indicates that magnetizing by shaft winding is not entirely satisfactory. Some blade rows may be magnetized properly, but others become magnetized in such a way that cracks have escaped detection. Also, shaft winding generally necessitates removal of the rotor from the casing, not always desirable.

We prefer to magnetize a segment of one or more rows at a time by means of magnets or external solenoids applied at the periphery of the rows. Special means developed for this type of magnetization have proved very satisfactory and practical—a new type coil designed to operate on ordinary lighting-circuit voltages adaptable to both A.C. and D.C. From 300 to 600 ampere-turns is usually sufficient.

Those experienced in the use of the process can readily determine if proper magnetization has been established by observing the even manner in which the powder adheres to the surfaces. Certain characteristic types of adherence usually evidenced by the collection of "streamers" standing out from the surface indicate improper magnetization, wherein the presence of a crack will have little or no effect on the powder.

The tendency has been to establish too great a flux density. In such cases, powder will be strongly attracted to the surface and deposit where it lands without regard to cracks. Quite feeble magnetization, if in the proper direction, is satisfactory. For example, the weak residual in soft-steel plating, not enough to be felt by the pull on a nail, will still show up cracks when dusted

[1] Metallurgist, Fidelity & Casualty Co. of New York.
[2] Duquesne Light Co., Pittsburgh, Pa. (Deceased).
[3] West Penn Power Co., Pittsburgh, Pa.
[4] Westinghouse Electric & Mfg. Co. (Deceased).

with powder. Test for magnetization by hanging a wrench at the shaft end may be meaningless.

The Magnaflux process has proved particularly useful for inspecting for cracks in disk wheels. The powder will show cracks which cannot be exposed by the ordinary whiting test. Fatigue cracks have initiated in both radial and circumferential directions, although, of course, they tend to follow a scalloped shape in the final stages. Initial radial cracks occur at the rim, particularly at the dowel pin at the start and stop point, and at the hub. Cracks at the equalizing holes are more apt to start off in a circumferential direction, as do other types of cracks at the rim.

Where steam balance holes permit, toroidal or "doughnut" winding for ring magnetization is more suitable for disclosing radial cracks. Open solenoid wrapping (not around the shaft between the disks, but enclosing a segment of the disk wheel) is preferable for checking circumferential cracks. The portable electromagnets are also efficient for detecting disk cracks in any location. It is not necessary to remove the rotor from the casing, but the work is facilitated by so doing.

STRADDLE-ROOT BUCKETS.

Cracks in the disk-rim tenon enclosed by straddle-root-type buckets cannot ordinarily be disclosed by the Magnaflux process without removing the buckets. Other magnetic or resistance methods hold little promise. About the only indication observable is the loosening or leaning of buckets or evidence of displacement at the root, and this only after the crack has become well developed. Inspection methods utilizing the change in vibratory characteristics are being investigated, but experience to date is insufficient to determine practicability.

Routine inspection for cracks in the rotor shaft itself is generally limited to the exposed areas, but as the fillets and changes in section between the journals and rotor body, where stress concentrations are to be expected are usually accessible, Magnaflux inspection does afford considerable protection. It must be recognized, however, that circumferential cracks may occur at unexpected locations.

Shaft cracks are readily exposed by magnetizing the shaft as the core of a solenoid. Coil location should be selected to discourage flux lines from emerging into the air normal to the surface being inspected. The portable electromagnets are also fully as useful for this inspection.

Failures of generator-rotor retaining rings have fortunately been rare, but when they do occur, the result is disastrous. Many rings retain sufficient residual magnetism for the test, but electromagnets are readily applied to magnetize in the direction suitable for disclosing cracks starting from the ends of the ring. Such cracks have already been found by the Magnaflux method. Inspection for cracks in fan blades and rings have also been made by this process. The "wet" method is generally used for these parts.

The question has been raised as to possible harm residual powder might cause when used on generator-rotor retaining rings, fans, etc. The total amount of powder for a large rotor probably does not exceed half a teaspoonful carefully applied to the surfaces, and is then wiped and blown off in the usual cleaning before reassembly. Curiously, the powder is a non-conductor due to its coating, and infinity megger readings have been noted with the terminals buried in a can of powder.

While it is not generally believed that a few particles of the fine powder which might remain after cleaning would cause any damage, practice is to use impalpable magnetic rouge in oil suspension (the wet method) for such applications. A thin film is applied with a brush.

REMOVING THE POWDER.

The question of removing Magnaflux powder from turbine rotors has also been raised. The author can see no possible harm from any residual powder remaining after the normal cleaning or blowing out every rotor gets. The bulk of the powder usually drops off when the magnetizing current is broken. Blades are often inspected with the rotor in the lower casing, when it is undesirable to do more than lift the cover. With reasonable care in protecting journals and bearings, and the ordinary cleaning following an overhaul, there should be no cause for concern in using the powder near these locations.

Hundreds of turbines have now been inspected by the Magnaflux process, and so far as the author is aware, there has not been a single case where damage has been attributed to presence of the powder. It is all fine enough to pass a hundred mesh, and the coating is inert. Any remaining powder would represent an extremely small part of the foreign matter normally circulating through any system. Obviously, the insurance carrier would be first to condemn questionable practice.

Demagnetization of turbine parts after an inspection is generally considered unnecessary. There has been no evidence of harmful accumulation of magnetic oxides or particles due to residual magnetism in disks, buckets, and blading.

The question of how often inspection must be made to insure against failures is difficult to answer. It depends on the time required for a crack to progress from an initial stage, undetectable by the process, to failure.

The first inception of a crack can be seen only with a microscope under favorable laboratory conditions, and is indicated by slippage along latice planes within a crystal. To be detected by the Magnaflux process, the slip has to develop into a definite crack involving a line of crystals, but cracks only a few thousandths of an inch long have been detected.

From this point on, the rate of progress of a crack depends on so many factors that no specific time limit can be set. We have learned of one case where blade failure occurred ten months after inspection, but there may have been some question here as to proper magnetization of the row involved. Other failures within a few months after inspection were due to sudden causes, as heavy tip rubbing.

Conceivably, under certain conditions, true fatigue cracks may initiate and progress to final failure within a few weeks' time, but such failures would be expected to occur shortly after installation. On parts in normal service for a year or more, it is believed that inspections made yearly should catch any cracks developed since the last inspection, before more serious damage is done.

The value of this magnetic test method cannot be seriously questioned. Within our own experience, it has been the means of averting many certain failures, and by the same token, affording assurance when the test result is negative.

RESIDUAL STRESSES DUE TO CIRCUMFERENTIAL WELDS IN PIPES.

Welded pipe joints show favorable characteristics in many severe service applications. The temperature effects of welding are a matter of concern to the designer as well as to the welding engineer. The October, 1938, issue of "Combustion," New York, N. Y., prints an abstract from a paper delivered by E. L. Eriksen and I. A. Wojtaszak at the Annual Meeting of the American Welding Society, 1938. The tests reported were made by the Department of Engineering Research of the University of Michigan.

Tests were made on a series of three welded specimens of 20-inch O.D. pipe having 1-inch wall thickness and four welded specimens of 8⅝-inch O.D. pipe with ½-inch wall thickness for the purpose of establishing the variation in the residual stresses produced primarily by stress-relieving, but also by other differences in the history of the specimens. The specimens were all 18 inches long and consisted of two 9-inch lengths of pipe joined by a circumferential electric arc weld; see Figure 1. All were of open-hearth, seamless steel with a carbon content not exceeding 0.30 per cent. Three of the specimens were stress-relieved at 1200 F. for 8 hours. A summary of the specimens follows:

Specimen No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Pipe size (O.D.), inches	20	20	20	8⅝	8⅝	8⅝	8⅝
Wall thickness, inches	1	1	1	½	½	½	½
Stress-relieved	Yes	No	No	Yes	No	Yes	No

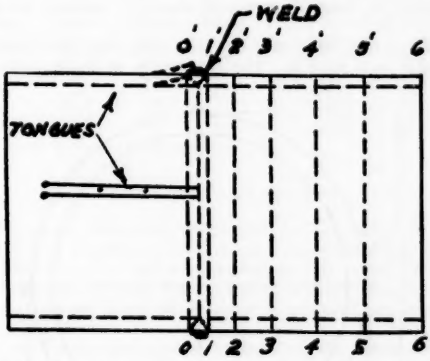


FIGURE 1.—DOTTED LINES INDICATE WHERE RINGS WERE CUT.

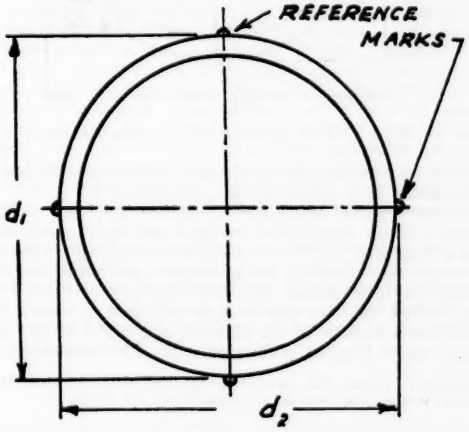


FIGURE 2.—SHOWING HOW MEAN DIAMETERS WERE DETERMINED.

The circumferential residual stresses were determined first by laying out a number of rings on one side of the weld as indicated by the dotted lines 0–0′, 1–1′ . . . 5–5′ in Figure 1. Reference marks were made at the ends of two perpendicular diameters of each ring (see Figure 2) and its mean diameter found.

Next, circumferential residual stresses in the pipe were released by cutting it up into rings along the sections indicated by the dotted lines and the new mean diameter for each determined. The released stresses, either compressive or tensile, were then arrived at from the increase in mean diameter of the rings by the formula

$$S_1 = E\frac{\Delta d_m}{d_m}.$$

Where S_1 is the stress released by this means, E is the modulus of elasticity, Δd_m the increase in mean diameter of the ring and d_m its original mean diameter.

Further residual circumferential stress in each ring was found by cutting it open as indicated in Figure 3. The stresses S_2 at the extreme fibers of the

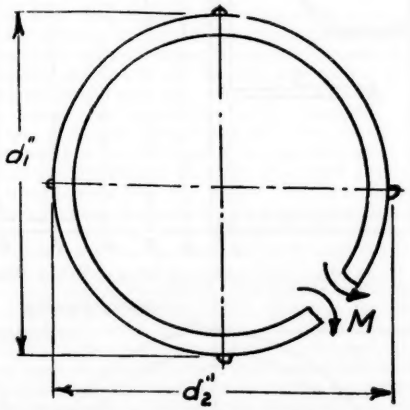


FIGURE 3.—RING CUT TO DETERMINE FURTHER RESIDUAL STRESS.

ring, released in this manner, are produced by a moment M, determinable by formula from which their magnitude was calculated.[1]

The total circumferential residual stress is then $S_1 + S_2$.

Determination of the longitudinal residual stresses is much more difficult and uncertain than that of the circumferential residual stresses. One can imagine a narrow ring including the weld and a portion of the pipe metal to be at the temperature of molten steel while the rest of the pipe is at room temperature. When this hot ring cools it will tend to shrink, but, since it cannot shrink freely because of the adjacent pipe metal, it will set up longitudinal stresses due to bending of the pipe wall. The longitudinal stresses set

[1] The original paper contains the several formulas and steps necessary for the calculations, but these as well as later formulas are omitted here for brevity.

up in this manner can be found by applying the theory of a beam on an elastic foundation.

In order to apply this theory to residual stresses in pipes due to welds, tongues were sawed in the walls of the pipe, as indicated in Figure 1, and readings were taken to ascertain the amount of deflection at the free end of the tongue. From equations applicable to deflection of such a beam the longitudinal residual stress was determined.

In the laboratory procedure involved in this investigation all measurements were made with the aid of microscope micrometers reading to 0.001 millimeters.

The results are given in the following table:

RESULTS OF TESTS

No. of Specimen	Outside Diameter, Inches	Wall Thickness, Inches	Stress-Relieved	Maximum Longitudinal Stress, Lb per Sq In.	Maximum Circumferential Stress, Lb per Sq In.
1	20	1	Yes	± 8,500	4,000
2	20	1	No	±50,000	32,000
3	20	1	No	±45,000	26,000
4	8⅝	½	Yes	± 3,500	2,500
5	8⅝	½	No	±24,000	17,000
6	8⅝	½	Yes	± 5,000	3,500
7	8⅝	½	No	±25,000	13,000

± Indicates tension or compression.

CONCLUSIONS AND REMARKS.

Probably the most important conclusion to be drawn from the results shown in the table is that the residual stresses are decidedly lowered by stress-relieving at 1200 F. It is to be remarked in this connection that tests by other investigators on 0.20 per cent carbon steel show that stress-relieving at 1200 F. tends to increase the ductility about 50 per cent and lower the ultimate strength about 30 per cent.

It may be mentioned that the magnitude of the circumferential stresses given in the table is quite possibly more accurate than that of the longitudinal stresses. The circumferential stresses were obtained by simply transforming the elastic recoveries into stress, while a more complicated theory was assumed in the calculation of the longitudinal stresses.

It is also disturbing to the investigator to find longitudinal stresses of 50,000 pounds per square inch a stress that is beyond the yield point of the pipe material as well as the weld material. This may indicate that the calculations of the longitudinal stresses mean very little or it may mean that there has been quite a considerable stress locked up in the original pipe before welding or that a certain amount of strain hardening has taken place.

In order to get a more definite picture of the stresses set up by the actual welding process, it seems necessary that a much more comprehensive study should be made including an investigation of the original residual stresses in the pipe.

Finally, suppose the 50,000 pounds per square inch stress simply means that the material at some place has passed beyond the yield point. How serious this is will depend on the use of the pipe. If the pipe is subjected to steady or static stress, it will probably not be serious. If, however, the pipe is subjected to fluctuating stress so that the question of fatigue comes into play it may have serious results.

BI-METAL CONSTRUCTION OF HIGH-TEMPERATURE STEAM VALVES.

E. R. Seabloom, Research Engineer of the Crane Company Research Laboratories, discusses the problem of materials for high-temperature steam valves in the Journal of the American Welding Society, New York, N. Y., November, 1938. Extracts from his article indicate the advantages gained from using special alloys for seating surfaces.

Valve manufacturers are constantly confronted with metallurgical problems which the ever increasing operating pressures and temperatures impose upon materials that enter into valve constructions. Within a relatively short span of years the pressures and temperatures in steam power plants have risen from 100 pounds per square inch at 338 degrees F. to 1500 pounds per square inch at 950 degrees F.

During this period of evolution the materials of component valve parts have undergone rather rapid changes to meet the continuous advancement of operating conditions. The bodies and bonnets, which comprise the pressure-containing shells of valves, have changed from cast irons, malleable irons and bronzes to cast and forged carbon steels and numerous types of alloy steels. The alloy steels used are of both the low-alloyed types containing such elements as nickel, chromium and molybdenum, and the high-alloyed austenitic types, depending upon the specific service requirements. The internal valve operating parts have also undergone notable changes, especially the seats and disks, which are subjected to the most severe abuse. In the early days these were made from bronzes, but as pressures and temperatures mounted it became necessary to continually adopt other materials or combinations of materials such as monel metal, cast nickel-copper-tin alloys, alloy steels, nitrided steels, stainless irons and finally the present ultimate of deposited surfacing alloys.

The general practice, at least by our company, is to employ deposited surfaces on disks and seats of all valves used on steam temperatures above 750 degrees F. Although numerous styles of valves are utilized in most piping installations, the bulk of production is in the gate and globe types, as these meet most requirements in controlling the flow of fluids. Consequently this paper will deal with the bi-metal construction of these two basic designs of valves.

SELECTION OF SEATING MATERIALS.

In valve construction the selection of seating materials is of vital importance, as these are subject to extremely severe service. In order for material to be regarded as satisfactory it should possess high resistance to erosion, abrasion and corrosion, withstand heavy loading without galling or seizing under high temperatures, and offer a fair degree of machineability, at least it must be readily ground and lapped. When the material is deposited it should flow out smoothly so as to minimize the amount applied and reduce the quantity of metal removed by machining or grinding.

One of the most salient properties that a seating material should have is high resistance to erosion as when valves are throttle or not tightly seated the velocity of the fluid flowing through the valve is increased tremendously, causing a serious erosive or "wire-drawing" action on the seating surfaces.

The relative erosion resistance of various ferrous and non-ferrous alloys has been determined by impingement of steam from a standard jet on specimens of the materials. Classification of the metals in relation to erosive properties

is accomplished by microscopically measuring the depths of the craters and by examining macrographs of the eroded specimens.

These investigations have indicated that hardness is not an index of a metal's resistance to erosion. This is evidenced in the nitrided steels, which have a hardness in the thousand Brinell hardness number range and offer low erosion resistance. The stainless irons and steels, while not particularly hard compared to the nitrided steels, display excellent resistance to erosion. In the case of deposited surface hardening materials it appears that alloys such as the cobalt-chromium-tungsten class give superior results over the cemented tungsten carbides or borides, even though there is a tremendous difference in hardness values. The poor resistance to erosion offered by surface hardening materials having hard particles suspended in a relatively soft ferrous matrix is due to the fact that the matrix itself has a very low resistance to erosion. From our observations it appears that erosion is probably the result of a combination of mechanical wear and corrosion of the metal surface by the fluid. That corrosion is a factor seems to be indicated by the excellent performance of stainless materials, which can be attributed to their high degree of corrosion resistance. Although numerous metals display superlative resistance to "wire-drawing" or erosion, they cannot always be used as valve seating materials because of their tendency to seize or "gall" when operated.

RESISTANCE TO SEIZURE.

In selecting seating materials for valves with sliding disks, such as gate valves, it is of prime importance that they have good bearing properties and retain their hardness at elevated temperatures so as not to seize or gall when operated under heavy loads. During the opening and closing operations on high-pressure valves the seating loads, caused by the line pressure acting on one side of the disk with atmospheric pressure on the other side, will exceed 20,000 pounds per square inch. If an improper material is used galling is bound to occur rapidly. The seating material, 12 per cent chromium iron, is an outstanding one as far as steam erosion is concerned, but is not suitable to operate against a material of similar characteristics in steam valves where no lubrication is obtained by the fluid. When a dissimilar metal is used with this type of material the results are much improved. However, in oil refinery service 12 per cent chromium iron is very satisfactory.

In order to determine the relative resistance of seating materials to galling, special test specimens are first subjected to a laboratory wear test in which the sliding action of a disk in a gate valve is simulated, the materials on test being rubbed together with a reciprocating motion while under constant load and in an atmosphere of steam at the desired temperature.

Materials which show definite promise in the preliminary laboratory experiments are further investigated in an actual service test by installing valves made up with these seating materials on a high-pressure steam line. The valves are then opened and closed either manually or by means of a motor-operated mechanism, blowing the steam to atmosphere, thus imposing heavy loads on the seating surfaces. These operations are continued until the seating surfaces fail or until the materials have proved satisfactory.

RESISTANCE TO ABRASION.

It is very desirable to use materials which have sufficient hardness to withstand scoring or indentation by scale and other hard foreign particles conveyed with the fluid which might become lodged between the seats during the opening or closing operations of a valve. The ability of a seating material to resist this action is a relatively simple matter to determine, as this quality is primarily based on the hardness of the material.

DEPOSITING OF COBALT-CHROMIUM-TUNGSTEN MATERIAL.

The usual practice, at least at the present, is to deposit this particular type of alloy manually by means of the oxyacetylene torch. This method of application produces smooth deposits and allows better control in preventing interalloying of the surfacing material with the base metal, which would otherwise lower the "redhardness" with consequent reduction in galling and abrasion resistance. The smaller disks and seats are mounted in rotating jaws or chucks which can be revolved at will by the operators by means of foot-controlled motor-driven gear reducers. Preheating is a very necessary requisite if cracking of the surfacing material is to be avoided and on smaller parts this is usually accomplished by means of the oxyacetylene flame prior to deposition of the alloy. On some small and intermediate size parts having relatively heavy cross sections the preheating is generally done in gas-fired furnaces, after which they are placed in the rotating machines for depositing. This results in more uniform temperatures and improved operating economies. In dealing with large parts, and also those made from certain types of alloy materials, which have peculiar cooling characteristics, it is necessary to maintain the preheating temperatures uniformly in specially constructed furnaces wherein it is possible to deposit the seating material simultaneously with preheating.

The procedure for surfacing with the oxyacetylene flame consists in bringing a small area of the preheated base metal to a sweating temperature. The end of the welding rod is then brought into the carburizing type of flame and allowed to melt and spread over the sweating surface. This operation is continued repeatedly by adding metal and the molten surface is spread by means of the welding flame. Our practice is to employ two or more passes, as smoother deposits, free from blow holes, are thereby obtained and overheating of the base metal is minimized so that grain growth is consequently reduced, making it unnecessary to heat-treat after depositing with most of the simple alloy steels.

COOLING.

The treatment after depositing also plays an important function in preventing cracking of the deposited material. Cracking is generally caused by differences in co-efficients of expansion between the surfacing material and the base metal, this being particularly true in the case of the more simple steels. However, some of the alloy steels, upon being heated above the critical temperature when depositing surfacing materials, undergo allotropic transformations during the cooling period.

MACHINING AND GRINDING.

Parts to receive surfacing material are first machined to predetermined dimensions with proper tolerances and allowances for shrinkage so that the finished deposited metal is from 1/16 inch to 3/32 inch in thickness, depending upon the size and design. Deposits are generally applied twice as thick in order to prevent surface irregularities from interfereing with the finished dimensions, which would otherwise necessitate resurfacing and add to the expense of the product.

The final finishing of the deposited metal is usually performed in several operations, depending upon the type of disk, body ring or valve body. Some are rough machined by means of tungsten carbide cutting tools, while others are rough ground prior to the finish grind.

After the various disks and rings are completed they are carefully examined and accurately checked for sizes and trueness by means of special gaging devices.

The parts are then assembled into valves and the contact bearing surfaces between the disks and rings are further checked by taking impressions with Prussian blue. If any slight irregularities exist they are removed by lapping to assure tightness on the hydrostatic and air pressure tests to which they are subjected before being stocked or sold to the consumer.

The application of deposited surfacing alloys of the cobalt-chromium-tungsten type to valve seats has vastly improved the reliability and operating life of valves in numerous installations where the service conditions are unusually severe, particularly in the modern high-pressure, high-temperature steam power plants.

The use of surfacing materials is constantly being extended, manifested by the fact that our company, aside from many others engaged in valve manufacture, produced in the last eight months of this year a total of 52,624 parts with surface alloy deposits. These consisted mainly of disks and seats which ranged in sizes from ¼ inch to 18 inches.

As pressures and temperatures increase it is safe to predict that further development of surface hardening materials will aid the valve manufacturer in coping with the serious problems that will be imposed on valve seats.

THE MARINE PROPELLER.

Here again a wealth of data from original research await synthesis by that rare and fluent personality, the engineering writer who increases the availability of information. The need is recognized in this article from the November 25, 1938, issue of "Engineering," London, England.

To the engineering mind there is something unsatisfying about the study of propellers. It is not the lack of finality, for that is inherent in all development, but rather a sense of frustration, that this excellent mechanical device should so persistently elude the refinement of simplification in design, which the engineer is taught to regard as one of his principal aims in life. For a given set of conditions, it is obvious, there must be some one combination of essential proportions that will produce optimum efficiency; and whatever the conditions, the behavior of the screw and the impressed behavior of the fluid in which it works must conform to the inflexible dictates of natural laws. Such limits apply to any engineering problem, and a majority of those arising in everyday practice can be brought to a commercially sufficient, if not a scientifically precise, solution by an attack directed along similar lines. But the conditions affecting the behavior of a marine propeller are numerous, and many are widely variable; to assess their combined influence demands a continuous integration that would be difficult enough if the conditions were accurately known and reasonably constant. Actually, they can never be constant for any appreciable length of time, and it is only gradually that experimental research is revealing the complex phenomena of the flow into, through and away from a propeller, when it is in position behind a moving hull.

The fundamentals of propeller theory were formulated by Rankine and Froude more than seventy years ago, but it is only since the general establishment of experiment tanks, and the development of sensitive recording apparatus for use in conjunction with them, that rapid progress has been

made in the correlation of model and full-size work. The acceleration of propeller investigations is well illustrated by the numbers of papers on the subject presented to the technical institutions of the maritime nations. Taking the Institution of Naval Architects as an example, in the first 25 volumes of its "Transactions" covering the period from 1860 to 1885, the index shows that there were 19 papers on propellers. In the next twenty-five years, 22 propeller papers were contributed, and in the third quarter-century there were 33 directly bearing upon the subject, in addition to many others on various aspects of ship propulsion, into which propeller design entered more or less incidentally. These figures relate to one institution only; when account is taken of the other scientific societies, most of them of more recent foundation, which are accepted media for the publication of official and private researches of this kind, the total of published papers, based on actual observation of model and full-size propellers, must now amount to many hundreds. It is an interesting commentary upon the state of the science of propeller design and construction, however, that the propellers with which the *Queen Mary* won the North Atlantic record weighed some 10 per cent less than those originally fitted to her and which, presumably, embodied the most advanced knowledge available when the vessel was constructed.

That the progress made is not more rapidly consolidated is largely due to the concurrent refinement of the experimental apparatus employed, with which may be included the mathematical processes by which observations are developed into theory and the theory applied to practice. One such forward step may sterilize a great deal of earlier data, until it can be re-examined under comparable conditions. Moreover, parallel development in the size, speed and powering of ships, and to a less extent, in the materials and methods of construction employed, require either extrapolation from existing information or the extension of previous researches to meet the new conditions. There was no reason to suppose, therefore, that the symposium of papers on the science of propeller design, which the North-East Coast Institution of Engineers and Shipbuilders arranged to hold last spring, would fail to attract a sufficiency of new material to occupy a two-days' meeting; and it is evident, now that the 10 papers and the discussion are available as a complete volume,[1] that the decision to hold the meeting has brought together information regarding a considerable amount of recent work, which otherwise would have entailed much labor to extract from the various reports and periodicals wherein such researches are normally enshrined.

Considering the papers as a whole, however, it is possible to feel a certain sympathy with the contributor to the discussion, who regretted that so much space was devoted to models and their measurements, and so little to the practical problems that confront the naval architect in designing a propeller for some particular ship, or in seeking the reasons for some shortcoming that it may display in service. The impression given by a first perusal of the papers is that the design of propellers, once the province of the engineer, and now the responsibility of the naval architect, is rapidly becoming the preserve of an exclusive sect of mathematicians, and that only those who are prepared to consecrate their lives to its study can hope to absorb the requisite knowledge or to acquire the skill necessary to apply it.

Such an impression is only partially warranted by the facts. It is probably true to say that at least three-quarters of the 30,000 or more propellers

[1] "Symposium on Propellers," 1938. Newcastle-on-Tyne, The North-East Coast Institution of Engineers and Shipbuilders. London: Messrs. E. and F. N. Spon, Limited. [Price 21s. net.]

at present in use on sea-going vessels could be improved upon to a material extent if critically examined in the light of the latest tank researches; but it is equally true that many satisfactory propellers have been and are being designed, without reference to the more elaborate mathematical investigations, by men whose competence lies rather in the ability to learn by their own and others' experience.

Professor Sir Westcott Abell, when opening the discussion, confirmed this fact from his personal experience, observing that he had not yet been able to design a bad propeller, "that is, a propeller which was distinctly bad." We believe that Rear-Admiral Dyson, U. S. N., after much close study of propeller problems, was led to comment in somewhat similar terms on the difficulty of designing a really bad propeller. "I have realized," continued Sir Westcott, "that it is possible to get a good average efficiency with an ordinary shape of blade with reasonable dimensions, and . . . that considerable research is necessary before I can hope to improve the average efficiency more than, say, 5 per cent." The complaint should not be that so much time and space is devoted to model work, in the "Transactions" of the learned institutions, but that so little is heard from those who have been successful, in everyday practice, in evolving a workable technique, combining the more readily applicable results of tank investigations with the practical experience which they alone possess. This, however, implies a much more communicative attitude, on the part of owners and superintendents, who are in a position to disclose service results, than has been in evidence in the past. No doubt much data of the kind has come into the possession of tank staffs, in the course of work done on private account, but, by reason of that circumstance, they are precluded from making public use of it. A greater freedom in this respect is a prime essential, however, if the experimental and the practical aspects of propeller design are not to become, in relation to ship propulsion, as widely separated as are astronomy and horology in the science of time measurement.

SIR CHARLES PARSONS AND MARINE PROPULSION.

The third Parsons Memorial Lecture was delivered at the Institution of Mechanical Engineers, England, on December 2, by Stanley S. Cook, B.A., F.R.S. The extract, published on 9 December, 1938, in "The Engineer," London, England, is reprinted here.

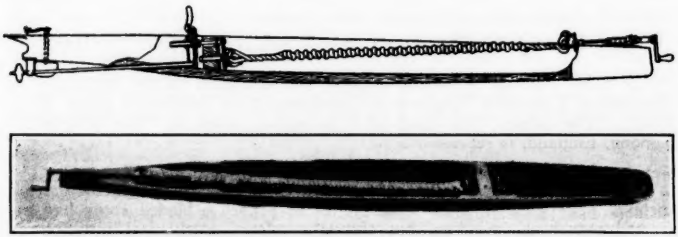
Many others before Parsons had attempted to make a satisfactory steam turbine. The idea of using a steam jet to propel a bladed rotor had attracted numerous inventors, but through lack of mechanical intuition or of the perseverance required for experiment, they failed to make a practical turbine. It is no part of this story to relate how Parsons by patient experimental work reached a satisfactory solution of the problem, and applied it, first of all, to small turbines for high-speed generators. In 1893, having after ten years of strenuous effort developed his compound steam turbine to such a degree that it had established its superiority over reciprocating steam engines, Parsons decided to attempt its introduction into the field of marine propulsion. The problem immediately arising was to reduce the speed of revolution of the turbine and to raise that of the screw to a common value without undue loss of efficiency. It was recognized that many other problems and difficulties were likely to be encountered and many prejudices required to be overcome in installing a turbine as the main pro-

pelling engine of a ship, and that the only satisfactory means of exploring and surmounting such difficulties was to build an experimental vessel. With characteristic energy Parsons set himself to the task of providing engines, boilers, hull, and all the equipment of a ship, making it his goal to drive a ship through the water at a record speed.

Some idea of his preliminary studies of the problem can be obtained from the illustrations accompanying the specification for a patent taken out in January, 1894. Preliminary studies, however, were not sufficient for Parsons; practical tests alone satisfied him, and for these he was full of simple and ingenious expedients. For example, to investigate the best forms of hull he constructed models, 2 feet long, which he towed by a fishing rod and line in a small pond at his residence at Ryton-on-Tyne. With these models he found that the hull with the rounded stern originally proposed tended to squat too much at the stern and rise at the bow. Later models in which this fault was corrected had propellers driven by clockwork and twisted rubber springs.

The resistance of the model was tested by towing it in a pond at the Heaton works with a salmon line and falling weights. The speed of the propeller was estimated by close observation of the time between double and treble knotting of the twisted rubber, which was found to represent a given number of revolutions.

Of particular interest is the 6 foot model illustrated in Figures 1 and 2, which is still in existence in the Museum of Science and Industry at Newcastle-upon-Tyne. It will be noted that in this model the propeller was driven through gearing. Its lines were later adopted for the hull of the *Turbinia*. A model of the *Turbinia's* hull was tested three years later in the Government tank at Portsmouth, and the effective power differed from that obtained in the above simple model only by from 2 to 3 per cent, a remarkable example of Parson's experimental skill with rudimentary apparatus.



FIGURES 1 AND 2.—SIX-FOOT MODEL FOR EXPERIMENTS ON TURBO-PROPULSION.

Meanwhile, Parsons was consulting with his friends on the all-important question of financing the venture, and early in January, 1894, the Marine Steam Turbine Company was formed with a private capital issue of £24,000. The directors were the Right Hon. the Earl of Rosse, the Hon. C. A. Parsons, N. G. Clayton, Christopher J. Leyland, J. B. Simpson, and A. A. Campbell Swinton. Parsons was appointed managing director. This company was a purely pioneer company formed for the purpose of carrying the financial burden and risk of the experiment. Parsons was fortunate in finding such excellent backing for his important venture into the realm of marine propulsion. In the meantime, the work of building had already commenced.

THE "TURBINIA."

As first constructed, the vessel had a single screw shaft, which was driven by a turbine of the radial flow type, to which type Parsons was for some time restricted on account of the retention of his patents for the parallel flow type by his former partners, Messrs. Clarke, Chapman and Co. (The patents were, in fact, recovered early in 1894, but in consequence of their temporary retention there was no experience of the performance of a parallel-flow turbine working with a condenser.) This turbine was being built at Heaton works, which were at that time busily occupied in the construction of turbo-generators. The boiler of the three-drum type, double-ended, was also tubed and tested at Heaton works, the drums being supplied by Messrs. Hawthorn, Leslie and Co. The hull was being built on a slipway at the sheet iron works of Messrs. Brown and Hood at Wallsend, an adjoining shed of which served later as headquarters for the trials. The boiler had 1100 square feet of heating surface, made up of straight tubes, ½-inch internal diameter, and two down tubes, 7 inches in diameter, thus ensuring intense thermal circulation. It was fitted with a superheater in the smoke-box, which, it may be mentioned here, was later removed, the superheat being found to be uncontrollable on account of flaming. The hull, of torpedo-boat form with U-shaped sections aft, was 100 feet long by 9 feet beam, and its displacement at 3 feet draught 44 tons. It was estimated that with this hull an effective power of 820 H.P. would be sufficient to give a speed of at least 30 knots. On the basis of a propulsive coefficient of 0.5 the boiler and turbine were designed to develop about 1650 H.P. The adjusting block of the turbine was also the main thrust block of the vessel, the residual steam thrust on the rotor being in the opposite direction to the thrust of the screw. The speed of the shaft was 1600-1700 R.P.M., which, it will easily be realized now, was both too low for the turbine and too high for the propeller to obtain a good performance from each. The propeller was 20 inches in diameter.

The work proceeded with great energy, and by November of that year the vessel and machinery were ready for trial. The first preliminary trial, carried out on November 14th, gave disappointing results. Changes were made in the propeller; in all, it is recorded that thirty-one different trials were made with different propellers—two-bladed, three-bladed, or four-bladed—and with as many as three propellers on the shaft. The last-named gave the best result, but this result was still disappointing. The best speed was just short of 20 knots.

At this stage we cannot fail to admire the indomitable courage of Parsons. One may hazard the opinion that with most engineers the experiments would have ended there. The gap between the estimated speed of 30 knots and the 20 knots actually obtained was an enormous one. The power varying as the cube of the speed, such a difference indicates a shortage of propulsive power in the ratio of 8 to 27. Faced with a failure of this magnitude, most men would have cut their losses, and in that case there might never have been a *Mauretania* or a *Lusitania,* no *Dreadnought* or *Super-Dreadnoughts,* no *Queen Mary*—who knows?

But Parsons here exhibited the courage and perseverance that later were recognized as outstanding elements of his character. First, to locate the cause of failure, he fitted a torsion-meter to the shaft. The greater part of the loss was found to be in the propeller, and it was soon recognized to be due to a phenomenon which had been just recently observed by Thornycroft and Barnaby during the trials of the 27-knot destroyer *Daring,* namely, cavitation of the propeller owing to the inability of the water to

close up on the back of the propeller blade. When the machinery for the *Turbinia* was designed, the *Daring's* trials had not taken place, and cavitation did not occur in the models at the reduced speed and pressure which corresponded with their size. Its occurrence in the full-size popeller was therefore unsuspected until it was disclosed by the trials of the *Turbinia* itself. In this connection, the following extract from a letter from Parsons to his brother, Lord Rosse, is of interest:

> In further reference to the propeller, the matter is now, I think, quite cleared up by a paper, proof of which I got this morning, by Thornycroft. He makes out from trials of the *Daring* and two other very high-speed boats that if the mean pressure of propulsion over the blade area exceeds 11¾ pounds, then vacuum, or as Froude has termed it, "cavitation," is set up, and the slip goes up enormously, as well as the power required for a given revolutions. In our present screw we had some 60 pounds per square inch mean pressure on the blades, and therefore enormous "cavitation" set up. I think the best course will be to follow out our patent and put two screws one abaft the other, the front one of, say, 19 inches pitch and the after one 22 inches pitch, so as to gradually accelerate the water column in two stages, also make the screws of the Archimedean form with maximum blade area and keep the diameter down to 28 inches. This is all very reassuring, as even in the *Daring* trials where the screw was working close to the point of commencement of "cavitation," an increase of 45 per cent in blade area put matters right and raised the speed from 24 to 29¼ knots with the same horsepower. We may, I hope, expect a much greater increase in our case. If two screws are not enough, we will put on more.

For a practical demonstration of cavitation on a model scale, Parsons devised a cavitation tank in which the propeller could be made to work under corresponding cavitating conditions. At first the water in the tank was heated to boiling temperature. In later experiments the surface of the water was exposed to a vacuum so that corresponding pressures were obtained as well as corresponding speeds. The tank was fitted with glass windows opposite the propeller and was illuminated by flashes reflected from a mirror revolving at the same speed as the propeller. In this way the phenomenon was brought under observation, and it was seen that under certain conditions, usually when the thrust per square inch of area exceeded a certain fraction of the pressure on the surface of the water, the propeller tore a hole in the water and revolved ineffectively.

Having demonstrated that propeller slip, thus increased through cavitation, was the cause of a serious loss of power, Parsons, with the loyal support of his pioneer company, determined on a fresh attack. The vessel was equipped with a new set of turbines, this time arranged on three shafts and of the parallel flow type. The shafts were each fitted with three propellers of 18 inches diameter and 24 inches pitch. Thus there were nine propellers of 18 inches diameter instead of the three of 20 inches in the first installation, making the disc area 2½ times as great as before. The three turbines were arranged in series, high pressure, intermediate pressure, and low pressure, so as to obtain the best turbine efficiency. Various devices were tried for the provision of astern power. In the first turbine a row of blades had been fitted in the rim of the last disc to receive steam from a nozzle projecting into the exhaust space. In the second set of turbines, astern blades were at first fitted inside the drum of the low-pressure turbine at the exhaust end, receiving steam from a nozzle projecting within the drum. This was, however, found insufficient, and finally a separate astern turbine was fitted on the center shaft forward of the low-pressure turbine. In all cases the rotor of the astern turbine or the astern rotor elements revolved in vacuum when going ahead, and likewise the ahead rotors were in vacuum when going astern.

The vessel was ready for trial with the new machinery in February, 1896, and after a few changes of propellers succeeded in attaining a speed of 32¾ knots—amply justifying the confidence and the perseverance of

Parsons and his helpers. In comparison with performances which are now commonplace, 32¾ knots does not appear a great speed, but it was a higher speed than had been reached by any vessel at that time. Later, with a larger funnel fitted to increase the steaming capacity, the speed was increased to 34 knots.

The *Turbinia's* appearance at the Naval Review in 1897 attracted universal attention and interest. The spectators may have been thrilled to see a tiny vessel racing down the lines at such unusual speed, but their feelings of excitement could have been nothing compared with those of the few on board the vessel, who had emerged so triumphantly from depressing failure into glorious success.

It may fittingly be mentioned here that the vessel was captained by the late Christopher Leyland, while Parsons himself was chief engineer, supported in the engine room by Dr. Gerald Stoney, who is the only present survivor of the crew of the *Turbinia* on that occasion, and who gave last year the second of this series of memorial lectures.

After a further demonstration had been made with the vessel at the Paris Exhibition of 1900, where before the French Minister of Marine full-speed runs were made on a wide reach of the Seine, the *Turbinia* had fulfilled her part in calling world-wide attention to the possibilities of turbine propulsion. She was used some six years later for some special experiments on propellers, and in 1908 was lifted on to the jetty at Turbinia Works, and there remained until 1927, an object of attraction to passengers along the Tyne. In 1927 the after part of the vessel containing the machinery was transported to the Science Museum at South Kensington, where, with a portion of one side of the hull replaced by glass plates to expose the engine room, she remains a striking exhibit.

The chief object of the propeller experiments just mentioned was to determine the value of having multiple propellers on a shaft. A series of runs was first made with the original nine propellers, when it was found that the speed and steam pressure followed exactly the same curve as that obtained by Professor Ewing six years previously, proving that no deterioration had taken place in the turbines, though the vessel had undergone many trials and had been taken to the Solent and back, and to Paris and back, in the interval. The propellers were then replaced by three others of 28 inches diameter, one on each shaft, and a better result was obtained. Although this was contrary to the conclusion reached in the case of the original machinery with a single shaft, where it was found that the best results were obtained with three propellers in tandem on the shaft, it is not surprising in view of the excessive cavitation of the single propeller in the former trials. Even in the second installation of the *Turbinia*, with propellers on three shafts running at the high speed of 2000 R.P.M., there was still a considerable degree of cavitation.

THE "COBRA" AND "VIPER."

The recovery of the patents for parallel flow turbines already mentioned, and the success of the *Turbinia's* latest trials, prepared the way for the application of the turbine mode of propulsion to warships. A new company was formed with the title of the Parsons Marine Steam Turbine Company, and with a nominal capital of £500,000. This company took over by purchase from the pioneer company the right to use the Parsons patents for marine propulsion, the *Turbinia*, and all effects. Of this new company, Parsons was managing director. The British Admiralty, whose attention had been drawn to the possibilities of turbine propulsion by the entry of the *Turbinia* into the Naval Review of 1897, showed keen interest in the

matter, and after a few further demonstration runs with that vessel attended by prominent representatives of the Admiralty engineering department, placed an order with the new company for the destroyer *Viper*, a 31-knot vessel of the same dimensions as the 30-knot destroyers then building, namely, 370 tons displacement, 210-feet length, and 21-feet beam, but with machinery of somewhat greater power to give increased speed. Illustrative of the difficulties which beset a great inventor and also of the confidence which Parsons had inspired in the members of his pioneer company, it may be related that at the meeting at which this contract was decided, the hopes of Parsons were considerably dashed when the Admiralty demanded an indemnity against failure in the sum of £100,000, but were restored again when Christopher Leyland went quietly across to him and said, "All right, Parsons, I'll back you."

At the same time, Sir W. G. Armstrong Whitworth and Co. also ordered from the company a set of machinery of similar power for a torpedo-boat destroyer which they were building and which was afterwards named the *Cobra*. These vessels each had four shafts, with duplicate sets of turbines on each side of the vessel, consisting of a high-pressure and low-pressure turbine in series to the steam flow, but on separate propeller shafts. They were equipped with boilers of a greater aggregate power than the other destroyers of the class, a greater weight being available for the boilers on account of the reduced weight of the machinery.

The *Cobra*, which was the first of these two vessels to be completed, was subjected to a large number of trials, including fuel consumption trials and special astern-going trials. She attained a maximum speed ahead of 34.32 knots and was eventually bought by the British Admiralty. The *Viper* when completed with full trial weights on board achieved a speed of 36.58 knots, more than 5 knots above the contract speed. As regards the coal consumption, which was guaranteed at 2.5 pounds of coal per indicated horse-power hour at 31 knots, she easily registered a consumption of 2.38 pounds. The smooth running of the turbines in both vessels, and the absence of the usual fuss and bother in the engine-room during trials of reciprocating engines, favorably impressed all the Admiralty officials present, who reported the trials as entirely satisfactory. Calamity, however, befell when these vessels were handed over. The *Viper*, which although completed later, was the first to be put into commission, ran on the rocks of Alderney in a dense fog in August, 1901, during reconnaissance work in the Channel Islands and became a total wreck. A month later the *Cobra*, while being taken by a navigating party from Newcastle to Portsmouth, broke her back and foundered in the North Sea.

PASSENGER BOATS AND LINERS.

Although the high speed of the turbine made it more suitable for fast warships than for passenger steamers, Parsons had from the beginning advocated its use for high-speed passenger vessels also, and had prepared models and plans of installations for various classes of such ships from channel steamers to ocean-going liners. But his advocacy of the new system evoked little response from shipowners until late in 1900, when he succeeded in enlisting the interest of Mr. Archibald Denny and Captain John Williamson in a proposal to build a turbine steamer for the Clyde passenger service. As a result a private syndicate was formed, shares in which were owned jointly by Captain John Williamson, Messrs. W. Denny and Brothers, and the Parsons Marine Steam Turbine Company, with the object of providing and running a turbine passenger steamer. (The syndicate was

afterwards merged into a company, Turbine Steamers, Ltd.) To the order of this syndicate a steamer, the *King Edward,* was put in hand, the hull and boilers to be built by Messrs. W. Denny and Brothers and the turbine machinery by Parsons. By June, 1901, this steamer was equipped and ready for trial. At the same time the Parsons Company had decided to put in hand another destroyer of the same power and speed as the *Viper.*

As examples both of enterprise and of foresight on the part of Parsons and his company, these facts are outstanding, and were vindicated in full measure in the circumstances which arose from the loss of the *Viper* and *Cobra.* This double misfortune within so short a period would have otherwise destroyed all the patient work of the preceding four years, and leaving them without a single example of turbine propulsion, would have threatened the collapse of the whole undertaking. But actually after this catastrophe there was still a turbine-propelled vessel, the *King Edward,* which had just completed its trials. This vessel attracted great attention by its performance in service as a Clyde river steamer, and the interest in turbine propulsion was maintained in the mercantile sphere; while interest was revived in naval work with the trials of the second *Viper,* which had been put in hand by the company and which, named the *Velox,* was later purchased by the Admiralty.

The success of the Clyde river steamer *King Edward* had far-reaching results. A second vessel was built by Messrs. W. Denny and Brothers for the same service, and a channel steamer was ordered from that firm by the South-Eastern and Chatham Railway for the Dover to Calais service. This vessel, named *The Queen,* attracted universal interest as an example of the new method of propulsion, and became a very popular vessel among travellers to and from the Continent, on account of her steady behavior and maintenance of schedule in heavy weather.

Other vessels followed in quick succession during an instructive period when the merits of the new method of propulsion were thoroughly tested in comparison with the older vessels on the same services; for example, *The Queen* on the Dover to Calais route of the South-Eastern and Chatham Railway, the *Brighton* in the Newhaven to Dieppe service of the London, Brighton and South Coast Railway, the *Princess Maud* on the Larne to Stranraer service, and the *Londonderry* on the Heysham to Belfast service of the Midland Railway.

Of special interest are four vessels ordered in 1903 from Messrs. W. Denny and Brothers for the British India Steam Navigation Company for service between the Persian Gulf and India, the *Lhasa, Linga, Lama* and *Lunka.* The manufacture of marine turbines up to this point had been carried out exclusively at the works of the Parsons Company under the personal direction of Parsons. Two of these four vessels, however, the *Lama* and *Lunka,* had turbines built by Messrs. Denny and Brothers under license from, and to the drawings of, the Parsons Company. Similar arrangements for building marine turbines under license were made with other firms, and thus began the extensive licensee connection under which the art of turbine building was taken up by the leading marine engine builders, not only of this country, but also of the principal countries of the world.

A further stage in advance was marked by the ordering of two Atlantic liners of 13,000 tons displacement for the Allan Line. These were the *Virginian* and the *Victorian.* The *Virginian* was built by Messrs. Alexander Stephen and Sons with turbines built by the Parsons Company and the *Victorian* by Messrs. Workman, Clark and Co., who themselves constructed the turbines under license.

RAPID PROGRESS.

Returning now to naval vessels, after the loss of the *Viper* and *Cobra* attention was concentrated on the destroyer *Velox*. It is a special requirement of naval vessels that they should not only operate economically at full speed, but also have a large cruising radius, which implies economy of steam consumption at a speed much below the full. To meet this condition Parsons first fitted to the inner shafts of the *Velox* small high-speed triple-expansion engines which could be disconnected from the propeller shafts above a certain speed. The steam from these triple-expansion engines exhausted through the turbines to the condensers of the main engines, developing additional power in the latter. This is noteworthy also as being the first application of the combination of reciprocating and turbine engines, afterwards more extensively applied in low-speed ships. The triple-expansion engines in the *Velox* were, however, replaced, on account of vibration, by high-pressure turbines, which have since become a normal feature in naval vessels, under the name of "cruising" turbines.

In 1902 the Admiralty ordered another destroyer, the *Eden*, which also had cruising turbines in addition to its main turbines. This destroyer was of the same size as the *Velox*, but, unlike the *Viper* and the *Velox*, it had a three-shaft installation of turbines similar to that of the *King Edward*. The cruising turbines, of which there were two, were coupled one to each outer shaft, and taking steam in series before exhausting it into the main turbines, were designated respectively the high-pressure cruising and intermediate-pressure cruising turbines. The Admiralty also decided as an experiment to adopt Parsons turbines in the *Amethyst*, one of four third-class cruisers of 10,000 I.H.P. then building, so that again the turbine was afforded an opportunity of showing its paces against its rival the reciprocating engine. The arrangement of the machinery in the *Amethyst* was similar to that of the *Eden*.

Interest in the new method of propulsion was at last thoroughly aroused. When in 1904 an agreement had been made between the Government and the Cunard Company to provide two vessels which would recover the supremacy of Great Britain on the Atlantic, a technical committee appointed by them to investigate and report on the most suitable type of machinery recommended the employment of the Parsons turbine, and it was decided to adopt it in the two new liners the *Lusitania* and *Mauretania*, each of 70,000 S.H.P. The boldness of this step and the confidence now felt in the ability of Parsons to surmount any difficulties which might arise under untried conditions are evidenced by the fact that at that time the largest marine turbines in service and available for the investigation of the committee were those of the Dover to Calais steamer *The Queen*, of 6000 S.H.P. Before, however, the commission had finally reported, the Cunard Company decided to fit Parsons turbines in one of two vessels of 21,000 I.H.P. then on order with Messrs. John Brown and Co., the *Carmania* and *Caronia*. The turbines of the *Carmania*, which were of similar arrangement to that of the *King Edward* and other Channel steamers, were built by Messrs. John Brown and Co. under license from the Parsons Company. It may be mentioned here that in the subsequent trials of these vessels after completion the *Carmania* was found to be about 15 per cent more economical in coal than the *Caronia*. As a preliminary to building these large turbines Messrs. John Brown and Co. also put in hand an experimental set of turbines of similar arrangement of 1530 I.H.P. for the sake of obtaining experience in their manufacture. This set of turbines was afterwards fitted in the Clyde river steamer *Atalanta*.

The introduction of the turbine for the propulsion of capital ships in the Navy was also the outcome of a committee of investigation appointed by the Admiralty in December, 1904, and presided over by the First Sea Lord, Admiral Sir John Fisher. This committee had available for investigation not only the turbine-driven Channel steamers then on service, but also the newly built destroyer *Eden* and cruiser *Amethyst*. Exhaustive trials of these vessels in comparison with their sister ships established the superiority of the turbines in economy at all but the lowest powers. Taking this fact in conjunction with other obvious advantages of the turbine, such as reduced weight and consequent reduction in displacement, absence of vibration giving a steadier gun platform, lower center of gravity of machinery and economy of personnel, the committee had no difficulty in recommending its adoption in cruisers and battleships, with the result that an order was placed with the Parsons Company for turbine machinery for a battleship, the *Dreadnought*, under sub-contract with Messrs. Vickers, Sons and Maxim, of Barrow. In anticipation of reduced steam consumption a reduction of about 15 per cent was made in the usual boiler proportions, an action which was fully justified afterwards by the trial results, the consumption of steam at full power for turbines only being 13.48 pounds per S.H.P. hour.

Parsons then turned his attention to the requirements of vessels of moderate speed. First of all, in 1908, he introduced the combined system in which the expansion of the steam exhausting from a reciprocating engine was continued in a low-pressure turbine, and then turned his attention to the question of some form of reduction gear which would enable both propeller and turbines to be designed for their best efficiency, and revived the idea of employing toothed wheel gearing of the double helical type for this purpose. He had actually used toothed gearing as far back as 1897 with the turbine of the small 10 H.P. launch of a yacht. This turbine was, in fact, the second marine turbine to be built, immediately following the construction of the *Turbinia's* machinery. The gear was single helical, one pinion connected to the turbine driving two gear wheels, each coupled to one of the twin propeller shafts.

THE "VESPASIAN."

To explore the difficulties attending the adoption of such transmission gear in a mercantile vessel, and to demonstrate its advantages, an existing steamer, the *Vespasian*, was purchased. The triple-expansion reciprocating engines already in the ship were submitted to careful efficiency trials and then replaced by turbines and mechanical gearing to drive the same propeller shaft and screw. A fresh series of trials was made with the new machinery, the results of which were published in a paper before the Institution of Naval Architects in 1910.[1] The toothed gearing, which consisted of a double helical gear wheel of 100 inches diameter driven by two pinions of 5 inches diameter, proved entirely satisfactory for the transmission of the full power of the machinery, namely, 1000 S.H.P., and the new machinery made an improvement of 15 per cent in the overall efficiency.

The success of the new system in the *Vespasian* led to its being adopted shortly afterwards in two Channel steamers, the *Hantonia* and the *Normannia*, on the Southampton to Havre service, built by the Fairfield Shipbuilding and Engineering Company, and in the steamer *Paris*, built by Messrs. W. Denny and Brothers for the London, Brighton and South Coast Railway. After these vessels had been successfully put in service the lead was quickly followed by other shipowners.

[1] The Hon. C. A. Parsons, "The Application of the Marine Steam Turbine and Mechanical Gearing to Merchant Ships," Trans., Inst. N.A., 1910 Vol. 52, page 168.

Although mechanical gearing was introduced primarily for the purpose of extending the field of utility of the turbine to the propulsion of low-speed vessels, the advantage of freeing the turbine from the limitations imposed on its speed by the low speed of the propeller was soon recognized to be of value, even in those fields then open to the direct-coupled turbine. The consequence was that the latter was shortly displaced, even in naval and high-speed mercantile vessels by the geared turbine.

The first immediate consequence of the introduction of gearing was an improvement in efficiency of marine turbines in all classes. The turbine, freed from the compulsion to run at the same speed of revolution as the propeller, could be designed for the speed of revolution which best suited it, and from this time on turbines even for large power were of smaller dimensions and of greatly increased efficiency. Turbines could be in series to steam flow and yet drive the same shaft; this subdivision of units was in itself an advantage, as well as being conducive to efficiency.

The gears of the *Vespasian* were cut by the Power Plant Company. But subsequently the Parsons company installed a gear-cutting plant, and was able to give attention to the special requirements of large-power high-speed transmission. The noise, which in the minds of most people was inseparable from toothed gearing, was found to be chiefly due to a small periodic error in pitch coinciding in frequency per revolution with the number of teeth in the master worm wheel of the gear-cutting machine, for the remedy of which Parsons soon supplied an ingenious solution by putting the motion of the work out of phase with that of the master wheel, so that these unavoidable errors were shifted in their incidence round the work in successive revolutions of the gear-cutting machine. This device, known as the "creeping table," is now in almost general use for the production of turbine gearing.

Shortly after the introduction of mechanical gearing by the trials of the *Vespasian*, two other forms of gearing were successfully put to experiment, the electric drive by Mavor in this country and by the General Electric Company in America, and the hydraulic transformer by Föttinger. Of these three systems of gearing, mechanical gearing, on account both of its superior efficiency and of its greater simplicity, has been the one most widely adopted.

After the war there was continuous progress in the direction of economy of fuel for ship propulsion, but competition in this direction began to be severe with the advent of the Diesel engine, which had a fuel consumption in the neighborhood of 0.4 pound per brake horsepower hour of oil. Still confident in the superiority of the steam turbine on mechanical grounds, Parsons considered the adoption of higher steam pressures, such as were already being employed for turbines in power stations. In a paper he read before the First World Power Conference at Wembley in 1924, he stated the case of high steam pressures for both land and marine work. In order to explore and promote its adoption in marine work, and with the co-operation of Turbine Steamers, Ltd., the same company that had co-operated in 1900 in the introduction of mercantile turbine propulsion by building the *King Edward*, a pioneer installation of high-pressure turbine machinery was fitted in a new Clyde steamer, the *King George V*. The installation consisted of geared turbines developing a power of 3500 S.H.P. on two shafts, designed for a boiler pressure of 550 pounds per square inch and a maximum temperature of 750 degrees F. This pressure was about twice as high as any previously adopted in marine work. Again, as in the *Turbinia*, the smallness of the power was not favorable to the best results, and this, in conjunction with the restricted spaces incidental to a fast river steamer and the exacting manoeuvering conditions due to frequent stoppage at piers, made the test of the new system a severe one. The experiment proved conclusively,

however, that high steam pressures could be safely applied to all classes of vessels, and from that time there has been a general increase in the steam pressure employed, although not yet to the extent that Parsons advocated. In the last year of his life he had the satisfaction of seeing the results of the adoption of a high-pressure system in a British destroyer, in which, with a boiler pressure of 500 pounds per square inch, the steam consumption was 7.7 pounds per shaft horsepower hour, and a fuel consumption as low as 0.60 pound oil per shaft horsepower hour was obtained, a new record for naval work.

It has been impossible in this brief sketch to do more than outline the work that Parsons did for marine propulsion. Reference has been made to certain vessels, whose names will ever remain historical as prototypes or pioneer vessels of the successive advances of turbine propulsion into marine work. At their head stands the *Turbinia*, the pioneer of pioneers. With the knowledge which we have today of turbine design and operation, largely derived from the work of Parsons, we cannot but be filled with admiration of his complete grasp from the first of the fundamental requirements of the problem, and the complete provision made for their solution in his earliest attempts with the *Turbinia*. The world is his debtor, not only for a wonderful piece of pioneering, but for the faith he had in his turbine, for his courage and perseverence in the face of difficulties to make it adaptable to all fields of marine propulsion, and for the wise provisions he made for the dissemination of his knowledge and experience. The work of building turbines for ships goes on, and we have had notable examples of it recently in the machinery of the *Queen Mary*, the *Nieuw Amsterdam* and the *Queen Elizabeth*. Parsons has won titles to fame in many spheres of applied science, but in none of brighter luster than in the field of marine propulsion.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

BETTER STEEL CASTINGS RESULT FROM HAVING FOUNDRYMEN CHECK DESIGNS.—Machinery, New York, N. Y., November, 1938.—(From an article by Carl F. Clarke, President and General Manager Monroe Steel Castings Co., Monroe, Mich., Member Steel Founders' Society of America.)

There is probably no single factor relating to the production of high-grade steel castings that is as important as proper design. Most designers possess the knowledge required to proportion steel castings. They know the different shrinkage factors applicable and the standard allowances. They are able to make a design that, theoretically, should produce a sound casting.

Unfortunately, the design problem is not quite so simple as that; there are other important considerations. First, there is the construction of patterns, the order for which may be given either to the foundry or to a commercial pattern shop. If the latter procedure is followed, the patterns may later have to be altered to accommodate them to the foundry methods or to the variables in shrinkage due to design. If the foundry makes the patterns, the buyer knows that they are going to be all that the foundry wants them to be. That saves time and often insures better castings.

Regardless of how perfect the pattern is, however, there remains one matter which, if overlooked, may still spell disappointment—a matter connected with design. Steel casting design details cannot be standardized, but some rules are fairly generally used; however, like all rules of procedure, there are important exceptions. Many of these are learned by the foundryman only after long years of experience. The foundryman has observed the behavior of molten steel in cavities of all kinds of sizes and shapes. By merely looking at a blueprint or pattern, he often knows instinctively whether a given section will run properly in the mold and produce a sound casting. Were he accorded the privilege of examining the pattern and encouraged to suggest any changes that he believed would improve the product, it would result in advantage to both foundry and buyer.

Too often the foundry is given a pattern that, in spite of the application of all the tricks of the ingenious foundryman, is incapable of producing first-quality castings, due to one or two defective features of design. If the foundryman is forced to make the best castings he can from the patterns sent in by the customer, that is one thing; but that procedure is not recommended if the best possible castings are desired. What we are concerned with is a means by which the buyer can communicate to the foundryman his willingness to cooperate in the matter of design.

This situation can be easily brought about. All this is necessary is to send a duplicate set of blueprints to the foundry with a note pinned to them reading something like this: "We are attaching an additional print and ask that you sign and return it as approval of the design, from the standpoint of sound foundry practice. Any suggestions for improvement in the design indicated on this print will be greatly appreciated." That sort of an approach will bring forth wholehearted cooperation on the part of the steel foundryman, who welcomes such opportunities to assist customers in getting the best possible designs.

It cannot always be determined in advance whether a given design, even when initially approved by a competent foundryman, will work out perfectly when the pattern is placed in production. However, an initial casting will usually tell the story. It can be cut up, checked, and tested, so that any design features that are causing trouble, which cannot be eliminated without some change in design, can be detected. Suggestions for alterations in design can then be made to the buyer, and when finally agreed upon, will usually result in more satisfactory castings.

Since a study of blueprints or even patterns does not always reveal the "bugs" in a given design, it would be appropriate for the foundryman to reply to a buyer's invitation for suggested improvements in design in some such manner as this: "Suggested changes are marked in crayon on this drawing. Further changes, helpful to foundry practice, may be suggested during the construction of the pattern or after sample castings have been made."

If the design is beyond the drawing stage and a pattern has been made, the foundryman might reply: "As far as we can determine, the design is satisfactory. However, changes may be necessary after sample castings have been made."

An excellent way to approach this question of proper design for steel castings is to call in a representative from the foundry while the drawing is still on the board and ask for his advice at the start. Many difficulties and much dissatisfaction could be avoided were this procedure more generally followed. Buyers adopting one of the methods suggested for cooperating with the steel foundryman on proper design will undoubtedly find that it pays real dividends in the prevention of delays and in the production of better castings.

VARIOUS NOISE LEVELS WITH THEIR EQUIVALENTS ON SHIPBOARD.—The British Motor Ship, London, England, December, 1938.—(Extract from a paper on Noise Reduction Experiments in Ships by S. R. Robinson, B.Sc., read at a meeting of the Institute of Marine Engineers.)

Types of noise (various)	*Noise level (phons)*	*Noises associated with Ships and Shipbuilding.*
Sound is painful about	130	
Aeroplane engine (18 ft. from airscrew)	125	
	114	Ship's siren
	113	Hammering on steel plate
	110	Boiler factory
Pneumatic drill	105	Engine room of Diesel ship (normal).
	104	Marine turbo-blowers
	102	Auxiliary generators
Heavy traffic in Mersey Tunnel	100	
London Underground Rly.	98	Turbine engine-room (near gear cases)
	93	Roller chain 1,000 r.p.m.
Ministry of Transport statutory limit for road vehicles	90	Engine-room of Diesel ship (sound insulated)
London traffic (very dense)	89	
	87	Machine shop
Typing office	85	Cabins near casings on Diesel ship (normal)
Automobile factory	82	
In noisy automobile at 30 m.p.h.	80	Cabins on Diesel ship (normal)
Moderate traffic in street	80	
Railway train	75	Smoke-room on Diesel ship
In quiet automobile 30 m.p.h.	70	
Ordinary conversation	65	Cabins on Diesel ship (insulated)
Quiet office	62	Cabins on large turbine driven liner
Street in suburb (no traffic)	45	
Country road (no traffic)	38	
Sitting still in quiet house	25	
In the country (very quiet)	15	
Threshold of hearing	0	

CARBON COPY.—Industrial Bulletin of Arthur D. Little, Inc., Cambridge, Mass., November, 1938.

The inertness of carbon and graphite to the action of chemicals, excepting those of a strongly oxidizing nature, has been known since the Middle Ages, but exploitation of this property in the process industries has been hitherto restricted because of the porosity of the fundamental forms in which the material was fabricated. This porosity is so great that carbon plates are used for some filtration operations. Now, however, fabricated tubing of non-porous, synthetic resin-impregnated carbon or graphite, through which many corrosive liquids may be safely transferred, has been

developed in sizes suitable for chemical engineering construction. The resin impregnation treatment does not affect adversely its resistance to electrical corrosion. The new material, moreover, possesses the additional advantage of greater mechanical strength without concomitant increase in electrical resistance. Tubing of impervious carbon or graphite is reported as capable of withstanding pressures ordinarily encountered in the process industries; it is further characterized by a very low coefficient of expansion, lightness in weight, and high resistance to thermal shock. Unlike ordinary carbon and graphite, the impervious carbon materials are not recommended for temperatures above 175 degrees C.

In all of these properties tubings produced from impervious carbon and graphite are virtually alike, with the single exception of heat conductivity, in which respect the graphite is distinctly superior. Comparative tests on new, clean tubings against other metals indicate that the rate of heat transfer of the graphite tubing, which lies between that of copper and that of steel, is better than that of many of the metals and alloys frequently employed in corrosion-resistant equipment. Since no formation of heat-resisting corrosion scale is anticipated on the graphite, it is assumed that over a period the rate of heat transfer through the graphite will approach even closer to that of copper.

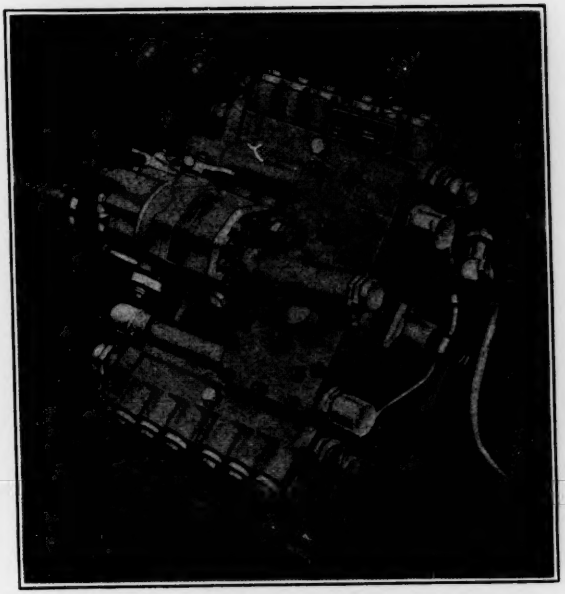
The new materials are available in standard sizes in lengths up to six feet, and six-inch inside diameter, plain, threaded or flanged, together with a line of fittings. It is reported that complete tube bundles of impervious graphite are now being supplied to manufacturers of heat exchangers. The development is new, and its progress will be watched with interest by the process industries.

PETROL-INJECTION MOTORS IN SERVICE.—The Aeroplane, London, England, October 19, 1938.

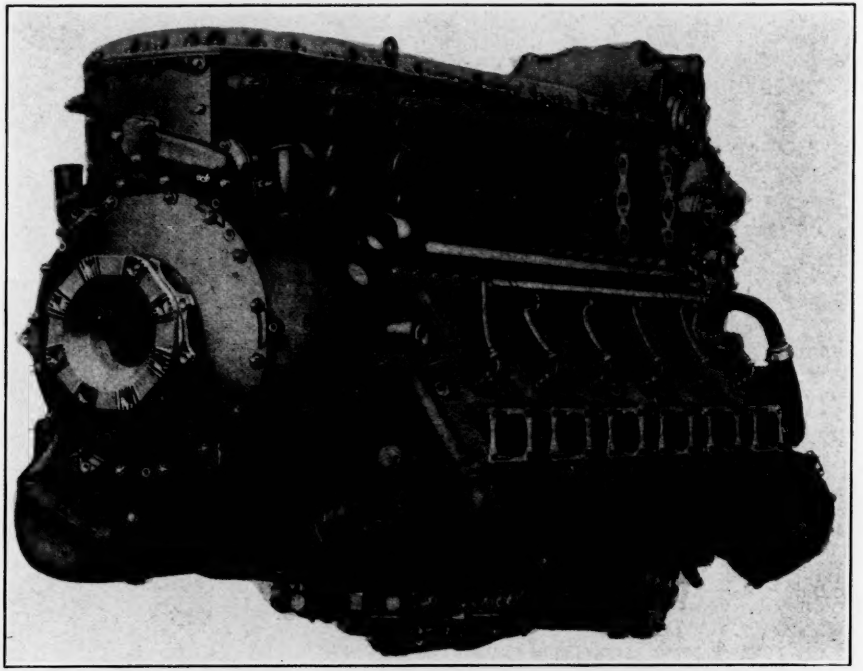
There has been a great deal of discussion about the merits or otherwise of replacing the carburetor on spark-fired petrol aero-motors by some system of fuel-injection. Those in favor of such replacement have argued that fuel-injection would improve economy and prevent icing-up. Those in opposition have argued that such advantages were offset by complication and cost and the difficulty of ensuring exact metering of the necessarily minute amounts of fuel. Some work has been done in the United States. Meanwhile the whole system has been put into practice in Germany. Here is the first information to be published about it.

Light-weight petrol-injection motors were built on a mass-production basis for fast power boats of the German Navy as early as 1917. The first engines of that type, the FO8 class, were the forerunners of both the Junkers Diesel aero-motors which at a later date acquired a well-deserved fame and the present-day Junkers high-output petrol-injection aero-motors of the 20 and 30-liter class.

The valuable experience which the Junkers Company had collected with injection pumps for oil engines during years of Diesel aero-motor development enabled them to make a quick and successful job in dealing with the particular problems inherent to the application of petrol injection. This marks an achievement that had been looked upon by the firm as one of paramount importance ever since 1916, although it has been kept aside for final development until the present day. It now comes just right to meet the increased demands upon the efficiency of aero-motors.



WORMSEYE VIEW.—THE TWELVE-CYLINDER FUEL-INJECTION PUMP UNIT OF THE JUNKERS JUMO 211 SEEN FROM BELOW.



CARBURETORLESS.—THE JUNKERS JUMO 211 OF 35 LITERS CAPACITY, WHICH IS GIVING 1100 H.P., HAS FUEL INJECTION PUMPS INSTEAD OF CARBURETORS. IT GIVES 1050 H.P. AT 5000 FEET.

Notwithstanding the high standard of perfection to which modern carburetor motors have attained, they are still afflicted with a number of deficiencies as regards the proper mixing and distribution of the fuel and air charge. As such difficulties have proved a check on the further increase of output, the problem must be considered to be serious.

The fact is known that in a carburetor motor the fuel and air charge is not uniformly distributed in the cylinders because the jet must be set so as to supply a properly saturated mixture to the cylinder which is the farthest away from the carburetor. As a result the other cylinders will receive a mixture which is too rich.

Now, as carburetor settings are made by groups of cylinders, the consequence is that there is considerable inequality of output as between individual cylinders. This is a drawback which prevents the taking of full advantage of the piston-swept volume. It cannot be reconciled with the demands made on modern high-speed aero-motors.

Moreover, the composition of the charge varies with the engine load. The transition from the no-load jet to the main jet during quick acceleration is rather unsatisfactory. The length of the intake pipes from the carburetor to the cylinder inlet-valves is in itself responsible for additional variation of the air and fuel proportions in the charge. Such variation is aggravated by the influence of temperature at different heights, let alone the effect of seasonal fluctuations of temperature.

The making of more or less complicated carburetor adjustments thus becomes necessary. Even then corrections for proper height will be found extremely difficult, if not impossible. When flying at considerable heights there is also danger of ice forming on the carburetor as the result of extremely low temperature. Finally, the presence of a highly explosive fuel-and-air mixture directly in front of the combustion chambers is another source of danger, as the carburetor may catch fire.

If we wish to eliminate all these deficiencies and at the same time to increase efficiency and economy, we have but one method. That is, to adopt the same procedure as in a Diesel motor, where the mixture is generated within the combustion-chamber, in other words to inject the petrol into the cylinder, which has previously received a charge of pure air.

ADVANTAGES OF INJECTION.

As in a petrol-injection motor, each cylinder has an injection element of its own which can be accurately set to meet the requirements, the charge is uniform in all cylinders and over the whole range of engine-speed. Contrary to the state of affairs in motors which have a carburetor where the control of the fuel-and-air composition is more or less inaccurate, a petrol-injection pump can be regulated in a technically sound manner.

Direct injection of the petrol and positive control of the fuel-and-air mixture completely eliminates all detrimental factors which are caused by fluctuations of temperature or change of weather. Moreover, with a petrol-injection motor there is no inconvenience caused by the transitory period in quick acceleration, because the injection pump can be set to a nicety so as to obtain utmost flexibility.

As the air ducts are much simpler than in a carburetor motor, the fuel supply to the cylinders is considerably improved. This is even more so because a high pressure is maintained in front of the intake-valves of a petrol-injection engine, as there is no throttling as in the case of a carburetor. This results in an increase of ceiling related to rated output.

Contrary to the characteristics of carburetor motors which necessitate flying at a definite rated height, injection motors will perform satisfactorily at any

CARBURETORLESS.—THE JUNKERS JUMO 211 OF 35 LITERS CAPACITY, WHICH IS GIVING 1100 H.P., HAS FUEL INJECTION PUMPS INSTEAD OF CARBURETORS. IT GIVES 1050 H.P. AT 5000 FEET.

desired height and are, therefore, specially adapted for military requirements. The danger of burning is considerably reduced, as no highly explosive mixture is generated outside the combustion chamber.

Direct injection also has a highly economical effect. Consumption figures are reduced by as much as 15 to 20 per cent, as compared with carburetor motors of equal power. This is the equivalent of an increase of range or disposable load for aeroplanes equipped with petrol-injection motors.

THE PUMP.

The Junkers petrol-injection pump has 12 cylinders arranged in two blocks suspended in the form of an inverted vee. Each block comprises six piston-pumps with fully automatic control. The drive is by a common camshaft, each cam of which actuates a pair of opposite pump-pistons.

The piston-travel is invariable and determined by the height of the cam. The pump delivery is controlled by changing the effective stroke. This is done by rotating the piston of each pump about its axis. The effect of this is such that its oblique edge bares the pump intake-port, earlier or later. The beginning of injection, therefore, is invariable regardless of quantity and, consequently, of engine speed.

Junkers injection pumps, as delivered ready for mounting, are set for equal delivery by all pistons. Readjustment after fitting the pump on the motor, therefore, is not necessary as a rule and should be avoided unless very special reasons make it advisable.

Lubrication and tight sealing of the pump-pistons is by oil taken from the forced-feed lubricating oil circuit. No ingress of oil into the fuel is to be feared. The pistons and cylinders are made to very close fits and every care is taken in the manufacture. As a further safeguard, relief-grooves are provided in the pistons. On the other hand, gradual infiltration of fuel into the oil-pipe when the motor is at a standstill is prevented by crack valves arranged in the injection-pump oil-circuit.

Fully automatic control of the quantity of fuel in relation to the weight of air aspirated by the motor is obtained by the Junkers injection-pump governor. Essentially this consists of a transmitter and servo part. Its function is to ensure the best possible performance with the lowest possible consumption of fuel whatever flying conditions may be encountered.

FUEL-INJECTION IN SERVICE.

Junkers petrol-injection motors have set up an excellent service record in the German Air Force even in the most adverse circumstances.

Practical demonstration of the merits of fuel-injection is shown by the performance figures for the Jumo 211 Ba and Da. The difference between Ba and Da is only one of reduction-gear ratio. Each has a two-speed supercharger with automatic boost-pressure control. The take-off power has been increased by 10 per cent in the fuel-injection version over that with the carburetor.

Cylinders.—Bore, 150 millimeters (5.91 inches); stroke, 165 millimeters (6.50 inches); capacity, 35 liters (2136 cubic inches); compression ratio, 6.5/1.

Airscrew Drive.—R.H. Tractor, 1:1.68 (Ba) or 1:1.55 (Da).

Dimensions.—Length, 1745 millimeters (68.70 inches); width, 804 millimeters (31.65 inches); height, 1059 millimeters (41.69 inches).

Weight.—615 kilograms (1356 pounds).

Performance.—Take-off at sea-level, 1100 H.P. at 2400 R.P.M. At 1500 meters (4921 feet): maximum, 1050 H.P. at 2300 R.P.M.; maximum

cruising, 940 H.P. at 2200 R.P.M.; cruising, 840 H.P. at 2100 R.P.M.; respective fuel consumptions, 213 grams (.470 pound), 203 grams (.448 pound), 203 grams (.448 pound). At 4750 meters (15,584 feet): maximum, 975 H.P. at 2300 R.P.M.; maximum cruising, 870 H.P. at 2200 R.P.M.; cruising, 805 H.P. at 2100 R.P.M.; respective fuel consumptions, 235 grams (.518 pound), 211 grams (.465 pound), 210 grams (.463 pound).

WATER-COOLED MERCURY VAPOR LAMP.—Pacific Marine Review, San Francisco, Calif., October, 1938.

A 1000-watt lamp no thicker than a lead pencil is offered by the Westinghouse Lamp Division, Westinghouse Electric & Manufacturing Company. A new principle is employed, mercury vapor in a very small "capillary" tube of quartz, operating at a very high pressure and water-cooled. The light it gives is exceedingly intense and concentrated.

This unique lamp is expected to be invaluable for use in photoengraving and other photographic processes as well as in searchlights and for therapeutic uses. Its rays are highly actinic and the amount of light emitted is high, 65,000 lumens. Moreover, since such a concentrated source can be focused with great accuracy, it should find application in many other projection fields. It is about 12 times as brilliant as a filament projection lamp. Never before has such a powerful, yet tiny, source of so high intrinsic brilliance been available.

The new lamp consists of a quartz tube about one-fourth inch in outside diameter, with a bore diameter of about one-twelfth of an inch. The tube contains a globule of mercury and is capped at each end with a brass ferrule which serves as a terminal. Wires project from each ferrule into the bore, leaving a gap of about one inch. In operation the lamp is to be surrounded by a glass jacket through which water is circulated. The design of this jacket will depend upon the maker of the equipment which incorporated the lamp.

This lamp may be operated on either direct or alternating current. Its voltage drop is about 840, at 1¼ amperes. Being a mercury arc lamp, it requires a ballast resistance when used on direct current, and a ballast impedence or ballast transformer when used on alternating current. It comes to full brilliance in one or two seconds. Its life when operated in a horizontal position on a schedule of 25 minutes on and 5 minutes off will be 50 hours.

Initial research on this type of capillary lamp was conducted by Philips Glow Lamp Works of Eindhoven, Holland; subsequent research and development in the Westinghouse Laboratories in Bloomfield, New Jersey.

MILLIONTH OF AN INCH.—General Electric Review, Schenectady, N. Y., November, 1938. (The article, "Measuring Millionths of an Inch in the Gage Room," is by Mel. C. Coffman, General Engineering Laboratory, and C. H. Borneman, Tool and Gage Service Department, General Electric Co. The introductory remarks, "Why a Millionth of an Inch," comprise an editorial in the same issue of the publication.)

WHY A MILLIONTH OF AN INCH.

In this issue Messrs. Coffman and Borneman describe a means which is used in a factory gage room to compare its primary standards of length in terms of millionths of an inch.

Why should a manufacturer be interested in so little as ±0.000001 of an inch? To answer this question one should begin by recalling the progress that has been made in producing and duplicating close fits.

In our grandfathers' time the conventional degree of accuracy in machine-shop practice was typified by calipers and scale. Then followed the micrometer; and later, for greater convenience in repetitive manufacture, the mechanical "go" and "no-go" gages. For today's superlative achievement of precision in mass production, electric gages are used. And, because these gages are capable of giving far more precise indications of manufacturing deviations than their predecessors, the standards by which they are set must be checked with far greater precision than formerly, if full advantage is to be taken of the greater capability of these new gages. This advance toward greater and greater precision in manufacture has brought us within sight of the stage where millionths of an inch are of significance in checking factory-gage-room standards of length.

Just how small is this new and finer unit of gage measurement? It is too small to be perceived physically, even with the aid of a vernier or a microscope. Resort may of course be had to the mathematical subterfuge of saying "It's a millionth of an inch." But what is an inch? A search for the answer to this question revealed the following interesting sidelights:

The first legal definition of the inch was made in England during the reign of Edward II in 1324 A.D. when a statute was enacted that three barleycorns (grains of barley) round and dry, when laid end to end equalled one inch; and that 12 inches made one foot. Exactly 500 years later, the yard was legally defined as the standard yard bar made by Bird in 1760, and provision was made that in the event it was destroyed another standard bar should be made based on reference to an invariable natural standard. The natural unit chosen was a pendulum vibrating seconds of mean time in the latitude of London in a vacuum at sea level. Huyghens in 1670 had conceived this plan when he discovered that the time of vibration of a pendulum is a function of its length. The English Parliament made the ratio of the yard to pendulum length 36 to 39.1393 inches.

Ten years later, in 1834, the Standard Yard was destroyed by fire. Meanwhile it had been conclusively proved that there were errors in the determination of the specific gravity of the original pendulum; the reduction to sea level was shown to have been doubtful; the reduction for the weight of air was also proved erroneous; and it was shown that sensible errors had been introduced in comparing the length of the pendulum with the standard bar. Since this time there has been no legal attempt to base a standard length unit on a natural unit. Both the yard and the meter are now based on standard length bars arbitrarily chosen, for there is no natural invariable standard for comparison.

The early crude standards, such as the arm of King Henry the First, a human foot, or a grain of barley, caused so much confusion that the foot length has varied from the Pythic of 9¾ inches to the Geneva of 19 inches.

In 1790 our Congress asked Secretary of State Thomas Jefferson to propose a plan for uniformity of measurements. Even before the adoption of the meter as the ten-millionth part of the quadrant of the earth's meridian, Jefferson foresaw the unreliability and inaccuracy of subdivision of the earth's quadrant, and proposed instead of the meter a decimal system of metrology based on the length of a simple straight bar which was suspended at one end as a pendulum. This pendulum was to be made from an iron rod and of such length that it would beat mean seconds of time under given conditions.

However, until 1866 no legislative action concerning length measurements was taken by our Government. At that time it was made lawful to use the

meter as the equivalent of 39.37 inches. There had been no other legislation, and so today we have the anomalous situation of a legalized meter that is not commonly used, and an inch that has never been formally legalized but is in common use.

Irrespective of this oddity, continual progress is being made in the art of precision measurements; and this advance is one of the essential factors in the development of civilization.

MEASURING MILLIONTHS OF AN INCH IN THE GAGE ROOM.

Higher standards of precision in length measurements are now possible through the recent application of a new General Electric electric gage head to the tailstock of a Pratt and Whitney measuring machine in the Schenectady Works Tool and Gage Department.

This machine was originally built to measure mechanically to 0.00001 inch the lengths of gage standards up to 80 inches and to compare differences in length, such as may exist between tool-room standards and factory gages.

Essentially, the machine consists of a heavy bed plate with a movable headstock toward the right end and toward the left a movable tailstock now equipped with an electric gage. Differences in length over 0.00001 inch are measured mechanically at the headstock; and by the combination of the tailstock and electric gage, differences as small as a millionth of an inch can be compared electrically. The electric gage is also used in setting the pressure on the gage standard being checked.

The frame of the machine has "vee-flat" ways accurately scraped on its surface to which are clamped the headstock and tail stock. Parallel to the ways and along the entire back of the frame is an 80-inch standard length bar in which is inserted a steel measuring button at each inch. On the polished surface of each button is a finely scribed line, precisely located with reference to the line on the zero button at the left end of the bar.

Mounted on the headstock is a microscope with two parallel hair lines for use in accurately positioning the headstock with reference to a given line on the bar. The headstock spindle is easily adjusted through the convenience of a micrometer screw on which a drum calibrated in ten-thousandths of an inch makes vernier readings to 0.00001 inch possible.

The tailstock is used as an end point in measuring gage lengths and once its zero position is set by the headstock it is rigidly clamped in place.

Before the application of the electric gage to the measuring machine, the accuracy of comparison and of measurement of gage lengths depended upon the ability of the operator to judge the pressure on the gage standard being measured between the headstock and tailstock spindles. When comparing or measuring two gages the gaging pressure should be the same. With this objective in view a small round steel bar called a drop plug was formerly used. The friction evidenced between the drop plug and the spindles was an approximate indication of the gaging pressure. The inherent insensitiveness of this method, coupled with the incenvenience of resetting the drop plug for each gage-pressure adjustment, made the application of the electric gage desirable.

The head of the electric gage is mounted on the tailstock in such a way that the gage spindle is the tailstock spindle. This makes the electric gage-head spindle responsive to the slightest variations in gaging pressure. Another feature of the design is the mechanically perfect alignment of the spindle during its entire travel. The extremely high sensitivity of the electric gage can thus be utilized in comparing gage standards to one-millionth of an inch difference in length.

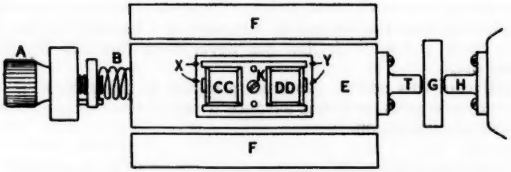


FIGURE 1.—DIAGRAMMATIC SKETCH OF THE ELECTRIC GAGE HEAD.

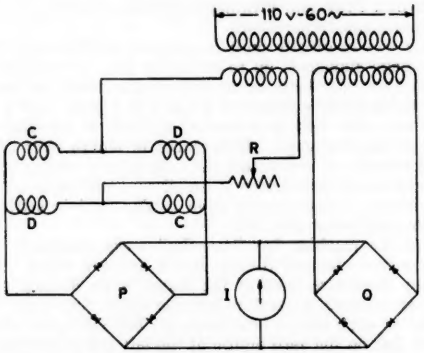


FIGURE 2.—CIRCUIT DIAGRAM.

As shown in the outline of the head (Figure 1) CC and DD are the gage coils; E is the armature, which is supported by flat springs from the frame FF; G is the gage block being measured between the tailstock gage-spindle T and the headstock spindle H; A is the screw which varies the compression of the spring B to adjust the gaging pressure on the gage block G to any desired value from 14 ounces to 4 pounds.

The solid steel armature E is free to move longitudinally on its supporting assembly of flat springs, which effectively prevents misalignment of the spindle T during the full travel of the armature. This method of support also eliminates mechanical hysteresis with its resulting errors in measurement.

The coil holder K, with the coils CC and DD, is rigidly attached to the tailstock frame, forming air gaps X and Y between the steel holder and the armature. Thus any lengthwise motion of the spindle T will increase one air gap and decrease the other. The accompanying changes in reluctance of the gage-coil magnetic circuits are measured by the unbalance occurring in an inductance bridge circuit consisting of the four windings in the two coils CC and DD.

Each gage coil has two windings, wound in multiple, and so connected in the bridge circuit that they are the diagonally opposite arms, C and C or D and D, as is shown in the simplified circuit diagram (Figure 2). As the armature moves, it varies the inductances of all four arms of the bridge simultaneously, cumulatively producing great circuit sensitivity.

The A.C. unbalance of the bridge is measured by a D.C. instrument I and a copper-oxide rectifier P in Figure 2. The rectifier Q supplies a circulating current through the rectifier P to make its operating resistance low, and cicuit sensitivity high.

The apparent disadvantage of rectifier currents flowing through the instrument in opposite directions was turned to practical benefit. An instrument with a zero-centered pointer was utilized because of its suitability for indicating directly plus and minus differences in length of gage standards. Quick precision measurements are thus made possible.

Zero indication on the instrument means that the currents from both rectifiers exactly cancel in the instrument, and this is possible only when the bridge is unbalanced the proper amount. It follows then that the bridge circuit is always unbalanced while in use and that gaging indications result only from varying the extent of unbalance.

By the sensitivity control R, the magnification ratio of gage indication to spindle movement is set to 25,000:1. Such a degree of accuracy in manufacture was undreamed of in James Watt's time, as is indicated by his boast that he couldn't shove a half-crown coin between the piston and cylinder wall of his steam engine. Today, high precision in the measurement and comparison of gages in the gage room is necessary to enable the factory to make products of better quality at lower cost.

A SIMPLE METHOD OF CALCULATING THE BENDING MOMENT ON PROPELLER BLADES.—The Shipbuilder and Marine Engine-builder, London, England, December, 1938. (An article by J. Lockwood Taylor, D.Sc., A.M.Inst.N.A., A.F.R.Ae.S.)

The usual method of estimating the bending moment due to thrust and torque (or the "hydrodynamic" bending moment, as it may be termed, on the aeronautical analogy, and to distinguish it from the bending moment due to centrifugal forces), according to marine practice, is to resolve the forces acting on the blade into thrust and torque components, calculate the bending action due to each separately, and then re-combine the component bending moments. Standard aeronautical practice, on the other hand, is to work in terms of the resultant forces at each section of the blade, and, regarding these as loads acting on a simple cantilever, to obtain the resultant bending moment directly by summation in the usual manner. This process requires a knowledge of the detailed distribution of load along the blade, which is not usually available for the average marine screw. By assuming a standard distribution of load, it is, however, possible to calculate very rapidly the resultant bending moment, and numerous detailed calculations show that the error involved in this assumption is inappreciable for all normal blades. A similar assumption is in any case implicit in the usual method, where the resultant thrust is assumed to act at a certain percentage of the screw radius from the boss.

The basis of the method is contained in the statement that the resultant of the bending moments at the roots of all the blades is simply the torque applied to the propeller. This statement becomes exact if the blades are regarded as extending to the shaft axis, as the shear force acting on the blade section does not then contribute to the torque. Hence, working back from the torque, which is known, the method gives directly a resultant blade bending moment acting at an imaginary section at the shaft axis; the moment at the actual blade root is derived by multiplying by a coefficient depending on the radius to the root section.

One further conception involved is that of the "typical" blade section, at which conditions can be regarded as representative of the blade as a whole, more particularly, in the present instance, as regards the direction of the resultant hydrodynamic force, *i. e.*, the resultant of the hydrodynamic lift and drag at the section. In practice, a representative section is that at 0.7 of the screw radius from the axis. The value of the angle $(\phi + \gamma)$ at this section (see accompanying diagram) is found by detailed analysis to be very nearly the same as for the blade as a whole.

The details of the method are as follows. The torque is expressed in terms of the delivered horsepower, P (*i. e.*, shaft horsepower at the screw, allowing for shaft losses) and revolutions per minute, N, as

$$\begin{aligned} Q &= 33{,}000\ P \div 2\pi N \\ &= 5{,}250\ P/N \text{ (foot pounds)} \\ \text{or} \quad &63{,}000\ P/N \text{ (inch pounds)} \end{aligned}$$

The "axis bending moment,"

$$M_0 = Q \div n.\sin(\phi + \gamma)$$

where n = number of blades. This follows from a simple resolution of the torque into its components.

The blade root bending moment

$$M = f.M_0$$

where the value of the factor f is found to be as below, for various boss diameters:

Root radius ÷ screw radius	0.15	0.20	0.25	0.30
Factor f	0.79	0.715	0.645	0.57

As regards the value of the angle $(\phi + \gamma)$, where a hydrodynamic analysis of the propeller has been carried out, the separate values of ϕ, the "angle of advance," and of γ, the "gliding angle" of the section, will be known and can be substituted. More generally, when only the overall screw efficiency is known, the value of the angle can be readily obtained by equating the efficiency to the standard expression

$$\begin{aligned} \eta &= J \div \pi x.\tan(\phi + \gamma) \\ &= J \div 2.2 \tan(\phi + \gamma) \end{aligned}$$

on putting x, the fractional radius at the typical section, equal to 0.7. Here J is the usual "advance constant," given by

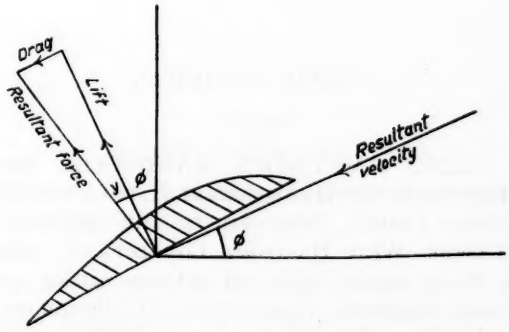
$$J = 101.3\ V \div ND$$

V being the speed of advance (ship speed less wake speed) in knots and D the screw diameter in feet.

Hence

$$\tan(\phi + \gamma) = J \div 2.2\eta$$

and the value of $(\phi + \gamma)$ and $\sin(\phi + \gamma)$ can be read from the trigonometrical tables.



As a numerical example, consider a four-bladed propeller, absorbing 1000 horsepower at 100 R.P.M., the speed of advance being 10 knots, and the screw efficiency 0.70. The diameter of such a propeller would be about 13 feet, and the pitch ratio about unity.

$$Q = 63{,}000 \times 1000 \div 100$$
$$= 630{,}000 \text{ inch pounds}$$
$$J = 101.3 \times 10 \div (100 \times 13)$$
$$= 0.78$$
$$\tan(\phi + \gamma) = 0.78 \div (2.2 \times 0.70)$$
$$= 0.506$$
$$(\phi + \gamma) = 26.85 \text{ degrees}$$
$$\sin(\phi + \gamma) = 0.452$$
$$M_0 = 630{,}000 \div (4 \times 0.452)$$
$$= 348{,}000 \text{ inch pounds}$$

Assuming a boss diameter ratio of 0.2,

$$M = 0.715 \times 348{,}000$$
$$= 248{,}000 \text{ inch pounds}$$

The simplicity of the method can be seen from the above numerical example. In addition to the hydrodynamic bending moment, for the usual type of blade which is raked aft, there is the centrifugal bending moment to be considered. It is proposed to deal with this in a subsequent article, but it may be stated that for propellers having a similar circumferential tip speed (*i. e.*, $N \times D$ constant), and angle of rake, stresses due to hydrodynamic forces alone give a fair indication of the relative blade strengths.

BOOK REVIEW.

THE RADIO AMATEUR'S HANDBOOK, SIXTEENTH (1939) EDITION, BY THE HEADQUARTERS STAFF OF THE AMERICAN RADIO RELAY LEAGUE, PUBLISHED BY THE AMERICAN RADIO RELAY LEAGUE, WEST HARTFORD, CONNECTICUT. 560 pages, including 6-page topical index and 104-page catalog section of amateur radio equipment. Approximately 815 illustrations and 50 charts and tables. Price, paper bound, $1.00 in Continental U. S. A., $1.25 elsewhere; buckram bound, $2.50. Reviewed by Lieutenant D. R. Hull, U. S. Navy.

This handbook is the sixteenth of an annual series prepared primarily for the radio amateur. As such, six of its twenty chapters are devoted solely to the fascinating field of amateur radio. The balance of the material is of general radio interest.

The chapters entitled "Elementary Radio Principles," "Radio Circuit Terms, Definitions and Equations," "Vacuum Tubes," and "Antennas" cover fundamentals in non-technical and very readable terminology. The several chapters on construction of equipment handle their subjects in progressive manner, starting with the more simple types of apparatus. Although constants given are for amateur frequency bands, the designs of equipment are indicative of the best in radio development. The appendix contains a number of convenient tabulations of radio symbols and data. A catalog section presents the principal products for amateur use produced by leading radio manufacturers.

This reviewer has found past editions of the Radio Amateur's Handbook extremely useful as a basic text for instruction of students with little mathematical foundation. The extensive revision of the sixteenth edition should make it even more valuable in this field.

ERRATA

It has been necessary to change the date of the Banquet to Thursday, April 13, 1939.

ASSOCIATION NOTES.

OFFICERS OF SOCIETY FOR 1939.

The following have been elected officers of the Society for the calendar year 1939:

President:

Rear Admiral S. M. Robinson, U. S. Navy.

Secretary-Treasurer:

Lieutenant Commander Guy Chadwick, U. S. Navy.

Members of Council:

Captain Bryson Bruce, U. S. Navy.
Captain J. M. Irish, U. S. Navy.
Commander E. L. Cochrane (CC), U. S. Navy.
Commander J. C. Odend'hal, U. S. Coast Guard.
Lieutenant Commander J. B. Dow, U. S. Navy.
Mr. George B. Ferrier.
Mr. Howard J. Ball.

ANNUAL BANQUET, 1939.

The Annual Banquet of the Society will be held at the Willard Hotel on Friday, April 7, 1939. The following will be the speakers:

Rear Admiral S. M. Robinson, U. S. Navy.
Commander Frederick W. Pennoyer, U. S. Navy.
Mr. Lawrence Y. Spear, Vice President, Electric Boat Company.
Dr. Charles F. Kettering, Vice President, General Motors Corporation.

The Toastmaster will be:

Commander Tully Shelley, U. S. Navy.

The Committee in charge of arrangements will comprise Captain J. M. Irish, Chairman, the remainder of the Council of the Society, Commander Tully Shelley, U. S. Navy; Mr. Charles G. Cooper and Mr. Harold K. Beck.

MEMBERSHIP.

The following have joined the Society since the publication of the November, 1939, JOURNAL:

NAVAL.

Adams, R. R., Vice President, Grace Lines, 10 Hanover Square, New York, N. Y.

Ambrose, Homer, Lieutenant, U. S. Navy.

Calahan, E. T., Lieutenant (jg.), U. S. Coast Guard.

Calvert, A. P., Lieutenant, U. S. Navy.

Chaffee, Hubert R., Lieutenant (jg.), U. S. Coast Guard.

Davis, Kenneth S., Lieutenant, U. S. Coast Guard.

Freeman, Walter C., Lieutenant, U. S. N. R., Apt. W32, 5101 39th Ave., Long Island City, N. Y.

German, John P., Lieutenant (jg.), U. S. Coast Guard.

Greer, Harry Holt, Jr., Lieutenant (jg.), U. S. Navy.

Haas, Peter W., Lieutenant Commander, U. S. Navy.

Harr, Myles F., Ensign, U. S. Navy.

Howe, Joseph, Lieutenant (jg.), U. S. Coast Guard.

Kirkpatrick, Claude S., Lieutenant (jg.), U. S. Navy.

McIntyre, Harris B., Lieutenant, U. S. N. R., Clifton P. O., Marblehead, Mass.

McKee, Logan, Lieutenant Commander, U. S. Navy.

Reynolds, G. R., Ensign, U. S. Coast Guard.

Righter, G. H., Lieut. U. S. N. R., Chief Engineer, S. S. *Chatham,* M. M. T. Co., Baltimore, Md.

Ryssy, J. W., Lieutenant, U. S. Coast Quard.

Simonson, Dale R., Lieutenant, U. S. Coast Guard.

Smith, Louis M., Lieutenant Commander, U. S. N. R., 34 Parkland Ave., Lynn, Mass.

CIVIL.

Carleton, H. E., Design Engineer, Foster Wheeler Corp., Tower Building, Washington, D. C.

Curran, James J., Research Metallurgist, Wallworth Co., Greensburg, Pa.

Gibbs, William Francis, Vice President, Gibbs & Cox, Inc., 1 Broadway, New York, N. Y.

Kurfess, W. F., Vice President, Just, Ryerson & Son, Inc., Chicago, Ill. Residence, 719 S. Garfield Ave., Hinsdale, Ill.

MacKrell, Franklin C., District Manager, American Locomotive Co., Diesel Engine Division, 20 Newbury St., Boston, Mass.

Olson, Charles A., Consulting Engineer, Engineering and Research Division, Crane Co., Chicago, Ill. Residence, 728 Shady Ave., Geneva, Ill.

Smith, Harry A., President, Engineering Specialties Corp., 39 Courtlandt St., New York, N. Y.

ASSOCIATE.

Coleby, F. J. A., Commander (E.), Royal British Navy, Assistand Naval Attaché, British Embassy, Washington, D. C.

Villanueva, Eduardo, Captain Engineer, Venezuelan Navy, Miraflores a Sta Barbara No. 57, Caracas, Venezuela.